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An Analytic Review of Personnel Models in the Department of Defense

D. L. Jaquette, G. R. Nelson, R. J. Smith

A report prepared for

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

Rand
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PREFACE

This report was prepared as part of Rand's DoD Training and Manpower Management Program, sponsored by the Human Resources Research Office of the Defense Advanced Research Projects Agency (ARPA). With manpower issues assuming an ever greater importance in defense planning and budgeting, the purpose of this research program is to develop broad strategies and specific solutions for dealing with present and future military manpower problems. This includes the development of new research methodologies for examining broad classes of manpower problems, as well as specific problem-oriented research. In addition to providing analysis of current and future manpower issues, it is hoped that this research program will contribute to a better general understanding of the manpower problems confronting the Department of Defense.

This report reviews the state of the art in DoD manpower modeling and analyzes the main contributions of models, present and future, to efficient high-level policymaking and decisionmaking.

The research began in the spring of 1974 and was completed early in 1976. Because manpower modeling is undergoing continual development, the most recent model variations may therefore have been unavoidably omitted. The broader conclusions drawn by the authors concerning the adequacy and future of the science of manpower modeling within the Department of Defense should, however, remain unchanged.

Because of the length of this report, nonspecialist readers may wish to confine their attention to Chap. 1, "Introduction," and Chap. 4, "Recommendations and Conclusions."

Research for and authorship of this report were allocated in the following manner: As project leader, Gary Nelson coordinated and supervised the research effort; David Jaquette wrote the material on optimization models; and Roberta Smith wrote the material on nonoptimization models.

SUMMARY

SUMMARY

The field of manpower and personnel administration has changed radically in the past decade. With the introduction of the All-Volunteer Force in 1972 and the general increase in pay, particularly first-term pay, the DoD has attached major importance to achieving efficiency in manpower management. The services have recognized the great promise of computer modeling for manpower control and planning; a compendium compiled by the Navy lists over 200 models, both large and small, that the services have developed for that purpose. This report examines 26 of those models in detail, following a review of the state of the art.

Useful though some of these models have been, most of them were developed sporadically, in isolation, to answer immediate and often narrow practical needs. The result has been an ad hoc, uneven, piecemeal approach to manpower modeling. That approach has been unavoidable, however, because no true science of manpower modeling has yet been developed to offer theoretical guidance.

A further penalty of fragmentation is the lack of coordination between models and the use of their results, a situation that can sow confusion among policymakers and even cause them to work against each other unknowingly. For example, if separate models are used to determine policies on promotion, retention, and accessions, the results may well be inconsistent with objectives for the whole force. The unification of approach, enlargement of policy areas, and development of scientific manpower modeling are prerequisite to rational and efficient use of models in high-level policymaking and decisionmaking.

This report is a first step toward those objectives. Rather than retrace the ground already covered by the Navy's exhaustive technical survey, the authors looked for models that hold promise for promoting efficient large-scale management and that illustrate the basic methodological and policy issues in manpower modeling. The eventual selection of 26 models resulted from consultation with modelers and personnel planners at Rand, the services and their contractors, and groups in the Office of the Secretary of Defense. Because the field is still innovative, continually producing new models, our selection was necessarily limited to models existing in various stages of development and application by 1975.

This study has four research objectives:

- To summarize the state of the art in manpower modeling and its current use in the DoD;
- To show how manpower models can make major contributions to efficiency in national defense, particularly through policies on training, retention, grade management, and compensation;
- To suggest how specific models may be applied most effectively to military manpower problems; and
- To suggest directions for the further development and refinement of existing models.

The 26 models selected fall into two main classes: optimization and nonoptimization, both of which have their appropriate uses. Optimization models are de-

signed to select the optimal value for a decision variable. They are programmed to accommodate policy changes and, for given performance criteria, to produce the best decision. If the planner fully understands the assumptions and limitations of the defined optimizing environment, he can use the models' results with assurance. Nonoptimization models only simulate the decisionmaking system and its results; they contain no built-in method for pointing to the best solution for a problem in policy analysis. In short, they are trial-and-error models.

Nonoptimization models serve in an ongoing heuristic process that acts as a surrogate for experience, enabling planners to test and evaluate decisions before they are implemented. For example, these simulations can output details on how a decision will affect critical points in the promotion and grade management system; the planner thereby can study peculiarities of the workings of the system without being concerned over good or bad effects. These models may be heavily dependent on a single type of data, however, such as loss rates, that predominantly drive the system—one of the limitations of this class of models that should be kept in mind in manpower management applications.

This report analyzes the capabilities of nonoptimization models in terms of their shared characteristics, stated as dichotomies: predictive versus ideal, entity versus aggregate, actual inventory versus derived distribution, deterministic versus stochastic. These concepts are used to explicate the state of the art in nonoptimization steady-state and dynamic models.

Because they are unique, the optimization models are analyzed individually here. They exhibit a wide range of assumptions, techniques, quality, and practicality. For example, goal programming achieves a balance of weighted deviations from the exact satisfaction of constraints. Although this technique has a certain practical simplicity, its limitations curtail application to concepts of large-scale efficiency.

Operational constraints from the practical decision environment limit the usefulness of all optimization techniques for achieving efficiency in large-scale planning. It is important that model builders and users evaluate the cost and efficiency penalty paid for strict adherence to operational constraints. Frequently, no feasible policy, let alone an optimal one, will be found that satisfies all constraints placed on the system. This problem could be partially solved by allowing operational constraints to vary along with other input parameters; the optimization models should then have a facility for sensitivity analysis of the ways in which large-scale policies would affect the varying operational constraints and input parameters.

This study's analysis found recurrent deficiencies in both optimization and nonoptimization models. Behavioral relationships were inadequately specified. Important feedback links were often ignored: factors such as historical retention, known to depend on policies affecting promotion and grade management, were not made functions of those policies in either type of model. Lack of validation, misuse of cost modeling, use of improper objectives or performance measures, an unnecessarily myopic view of potential policy parameters, extensions of models beyond the area of valid implementation, and inadequate and misleading documentation were all encountered.

It is hoped that this study will be a helpful guide to the users of models—managers and decisionmakers—through the maze of manpower modeling terms, limitations, and practical pitfalls. The findings should also be useful to model builders, designers, and programmers in a prescriptive sense. Above all, they should

clearly understand, and their models should accurately reflect, the decentralized military decisionmaking environment the models are intended to serve. All assumptions must be made explicit and must be justified. Such models will be flexible and versatile, endowed with transferability and adaptability that will enable their integration within the decisionmaking hierarchy when changes are to be made through the institution of new policies, parameters, or constraints from higher authority.

In summary, the science of manpower modeling and its contribution to efficiency in large-scale planning will develop and improve if model builders follow these fundamental guidelines:

- Describe the decisionmaking hierarchy and the subsystem where decentralized decisionmaking is to be improved.
- Make assumptions explicit regarding the following elements, and justify them as appropriate in the modeled environment:
  - Productivity measures of military effectiveness;
  - Requirements and constraints;
  - Supply of manpower;
  - Costing methodology;
  - Management objectives.

ACKNOWLEDGMENTS

The authors wish to thank the many people who provided assistance during the course of this study. These include many individuals from military and civilian government agencies and their contractors who spent numerous hours describing their models and discussing their views on the potential of manpower models for efficient, large-scale planning.

The authors gratefully acknowledge the continual support and suggestions provided by Richard V. L. Cooper over the course of the study. The authors especially wish to thank Grace Carter and Bernard Rostker for their thoughtful and constructive criticisms of an earlier draft of the report.

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Chapter 1

INTRODUCTION

Radical changes in the past two decades have rendered the field of manpower and personnel administration increasingly technical and complex. One consequence has been the growing dependence of administrators, planners, and other decision-makers, particularly in the Department of Defense, on mathematical models of *manpower and personnel systems*. Within the past ten years the military services and the Office of the Secretary of Defense (OSD) have developed models to assist in grade management, in the determination of promotion policies, in forecasting losses from the active force and requirements for new accessions, and in scheduling personnel inputs to training courses.

This modeling work has developed in parallel with high-speed digital computers. It is a natural extension of new capabilities in data processing, reflected in the computerization of military personnel data. Automatic procedures, often encapsulated in the form of mathematical models, have replaced what previously were clerical human functions. Because new computer capabilities have also greatly widened the opportunities for control and planning, manpower and personnel modeling has undertaken functions not previously performed within DoD.

Some of the more innovative developments in manpower modeling, particularly in models that seek to determine the "best" (optimal) policies, have employed analytical techniques borrowed from operations research and to a lesser extent from mathematical economics. The precepts of resource analysis have been applied in an effort to achieve "efficiency" in manpower and personnel management. Mathematical tools and techniques developed during the postwar era have been successfully applied to this kind of policy analysis.

Recent developments in military manpower have highlighted the importance of enhancing managerial efficiency in military force planning. Manpower costs as a proportion of the DoD budget rose from 27.7 percent in 1964 to 30.3 percent in 1974, creating concern in the services, the Defense community as a whole, the Executive branch and the Congress. Although most of the cost increase is attributable to general economic factors, part of it is due to the All-Volunteer Force (AVF), which officially began July 1, 1973, but which has been in progress since the formation of the President's Commission in 1969. More important than cost, the AVF has eliminated a guaranteed supply of personnel through the Selective Service System. The uncertainty of enlistments under the AVF places a premium on careful planning and good manpower management. The AVF will certainly require a fuller integration of loss and accession management. Manpower management has been made all the more difficult by the disruptive effects of the Southeast Asia conflict on retention rates.

POLICYMAKING AND MANPOWER MODELS

Although several hundred computer-oriented manpower and personnel models have been identified within the DoD, manpower modeling is not a unified field with

a common methodology. Most manpower models have been developed to solve specific problems or to meet specific needs for projections. This piecemeal development has not been governed by a true science of manpower modeling with a methodology based on accepted axioms of model construction.

On a more heuristic level, DoD manpower and personnel modeling is often a pragmatic exercise, closely linked to data sources and data processing efforts, where behavioral and mathematical assumptions are seldom explicitly stated. Underlying the many nonoptimization models is an implicit assumption, rarely tested formally, that good or even optimal results will somehow emerge.

Most models are developed to solve specific problems within a narrow focus of policy. For example, separate models may be used to determine promotion policy or retention objectives or accessions, with little coordination among the policy areas. At a minimum, models used in formulating policies should produce results consistent with the objectives for efficient management of the whole force; and the management of subsystems (grade structure, for example) must conform to overall defense objectives. But it is very difficult for the model builder to insure that such conditions are met.

More systematic and more comprehensive manpower models are needed to cope with chronic planning problems such as personnel costing, the structure of military specialties, and the integration of losses and accessions under the AVF. The hundreds of existing models were not designed with comprehensive planning in mind; still worse, the models tend to be short-lived. They often simply die when their authors are transferred, and thus lose even their limited usefulness. This has severely limited the effectiveness of manpower modeling in the DoD.

THE NEED FOR A REVIEW OF MANPOWER MODELS

Given the state of the art, it seems an appropriate time to undertake both a descriptive and an analytical review of manpower models, and thereby evaluate the capability of the field to meet DoD planning needs now and over the next decade. In our judgment, the quality of the research to date has been only intermittently good. Because critically reviewing all of the hundreds of manpower models would be a task both huge and unnecessary, we have confined our attention to a representative sampling.

Our review attempts to identify the most important issues and problem areas for manpower and personnel management that can be addressed with models. One of the most important areas has to do with long-term considerations of manpower and personnel policy. Management must be studied in a long-term context because the military is essentially a closed system that obtains trained, experienced personnel only from within. In such a system, changes in manpower or personnel policy have their strongest effects in the long term. Although the short-term effects of the AVF have highlighted the need to replace the accessions produced by the draft, the long-term adjustments in career force management may be more important. In the long term the DoD will have to adjust to trends in civilian wage rates, to secular trends in attitudes toward military service among young men and women, and to the significant decline in the size of age cohorts coming to the enlistment point during the 1980s.

Accordingly, we look principally at models that can be used to explore policies related to efficient force composition by length of service, pay grade, or rank, and policies affecting initial accessions (hiring), retention, and promotion. For the most part we exclude requirements, assignments, and purely forecasting models; policy decisions at that level may be determinants of overall force characteristics such as cost, efficiency, and retention behavior, but the models do not address those policies directly.

A potentially important omission in our review is the interaction between a manpower model and its users. People, not models, formulate and implement policy. A model is an instrument that supplies inputs to policymakers. Sometimes the instrument is known to be imperfect but is still highly useful. In such cases the user exercises judgment, judiciously modifying the model's outputs in arriving at policy decisions. That process lies beyond the purview of this study; consequently, we cannot pretend to pass judgment on the accuracy or wisdom of policies emerging from the process.

The research strategy undertaken here concentrates almost solely on the fundamental aspects of the models. This approach is justified by two important considerations. A complete study of the model-user system would have required elaborate interviewing and site visitation that were for practical reasons infeasible. Moveover, it is not always possible to identify the users. Many of the models are in the developmental process, with no user group clearly defined as yet, while others may have many users.

On the positive side, we did not believe this type of multifaceted study was vital to our research. Our work will have amply served its purpose if it leads to improved mathematical models for the policymaker. An accurate tool is always better than a flawed one in the hands of any user.

In sum, we had four main research objectives:

1. To review the state of the art, the most recent advances, and the current use of DoD manpower and personnel modeling;
2. To show how current models can promote efficiency in national defense, particularly through policies with respect to training, retention, grade management, and compensation;
3. To suggest how specific models may be applied most effectively to military manpower problems; and
4. To suggest directions for the further development and refinement of existing models.

Our sample consists of 26 models. Of these, six are optimization models and twenty are nonoptimization models, i.e., models not based explicitly on optimization procedures. Because many of the models have numerous antecedents and progeny, any single model may be representative of many other existing models. (See Chaps. 5 and 6 for details.)

Chapter 2 discusses the philosophical basis of our review, analysis, and criticism of models, and defines more precisely such terms as "efficiency," "optimality," "policies," and "variables," which are used rather loosely in this chapter.

Chapter 3 reviews the current state of the art without delving into the details of individual models. It also examines practical and theoretical problems commonly encountered in the development and implementation of manpower models. Chap-

ter 4 describes crucial components that should be common to all usable manpower models, and presents recommendations for model builders, users, and funders.

Chapters 5 and 6 review the individual manpower models and their weaknesses and strengths. The appendixes encompass a technical survey of the optimization models, a discussion of discounting, and the technical criteria for evaluating models proposed by the Naval Personnel Research and Development Laboratory.

Chapter 2

A METHODOLOGICAL BASIS FOR THE REVIEW

MANPOWER MANAGEMENT AND POLICIES

Manpower management is the art and science of formulating, choosing, and implementing policies affecting the manpower and personnel of an organization while supporting the goals and objectives of the organization.[1] The model is one of the tools the manager can use for that purpose.

A model can generally be viewed as "a mathematical or physical system, obeying certain specified conditions, whose behavior is used to understand a physical, biological, or social system to which it is analogous in some way."[2] In personnel management, it is most often a mathematical model that represents some facet of the personnel system and is used to relate policies to outcomes for the system. Models have been applied to requirements, accessions, retention, promotion or grade management, assignment, rotation, and compensation. The Navy Personnel Research and Development Laboratory (NPRDL) has produced a compendium of over 200 computer-based manpower and personnel models developed in the DoD [1,2]. The compendium remains a useful introduction to the breadth and scope of DoD manpower modeling.

A model can be classified either by the technical mathematics upon which it is based, or by its intended purpose, which is of more immediate interest to the potential user. Models developed so far are intended for use in (1) determining manpower requirements, (2) managing the active force (assignments), and (3) forecasting future manpower inventories. Models may be used in any of three modes: (1) simple description or prediction, (2) simulation of the effects of policies as a guide to choosing policies, and (3) formal mathematical optimization over a set of possible policies.

CLASSIFICATION OF PERSONNEL MODELS

Requirements models calculate the type and skill of personnel required to meet operational objectives. For example, models are used to calculate training facility staffing requirements as a function of accessions, repairmen as a function of flying hours, and accession requirements to staff the operating force.

[1] The usual dichotomy between manpower and personnel assigns to manpower such job-related functions as the setting of manpower requirements, the specification of jobs or billets, and the determination of skill levels or other qualifications for personnel assigned to particular jobs. Requirements models calculate the types and skills of personnel required to meet certain operational objectives. These models are used, for example, in calculating training facility staffing requirements as a function of accessions, repairmen as a function of flying hours, and accessions requirements to staff the operating force. The personnel function includes hiring, advancement, retention, and other activities directly related to people. Training may be viewed as belonging to either manpower or personnel; in truth it belongs partly to both. We are primarily interested in what are called personnel models, but draw no careful distinction between manpower and personnel models.

[2] McGraw-Hill *Dictionary of Scientific and Technical Terms*.

Models for managing the present force start with its current inventory, and then apply policies and natural manpower flow. Such models take a variety of forms depending on the detail required. Duty station or rotation models, assignment models, training or school-scheduling models all deal with the current force and aid planners in making decisions that take due consideration of personal objectives and skills requirements. Assignment models attempt to schedule training and achieve certain objectives such as equality in personnel rotation. Models of this type can determine the allocation of accessions to career field specialty according to aptitude or individual requests.

Forecasting models are used to predict important performance measures of the system, primarily budget costs and men. For example, models for forecasting retirement costs are of this type. Accession and retention behavior can be predicted by econometric models using personal characteristics of servicemen; so can force composition, given historical retention, promotion, and other variables. We make no distinction between forecasting, descriptive, and predictive models within this general class of models.

Projecting current force composition and its dynamic changes into the future requires knowledge of enlistment and reenlistment behavior as a function of personal characteristics such as age, education, and home town, as well as military grade, specialty, and length of service. Models that estimate retention within the force become a major component of the third category of personnel models. This category projects the personnel inventory into the future either in the longer-term "steady state" or during shorter periods (five years, for instance), called the "transient" period. Such models are used to predict how changes in personnel policy will affect the force, or are used simply to anticipate problems that may arise with the natural aging of the force.

Most DoD manpower models in these three categories are concerned with description and prediction of some small part of the total force. An occasional model uses optimization, or at least simulation, to determine some better manpower policy. In the Navy compendium the authors found that "these models, naturally enough, are limited in scope to the local concerns of the developers. Such local suboptimization within the manpower/personnel management community does not promise to add up to global effectiveness within the total . . . organization" [1, p. 145].

Certain models in the forecasting category are often used in simulation experiments. Following a series of computer runs, planning analysts review the output and feed back policy changes as new input. Planners can then make modifications to manpower policy in the form of promotions, training inputs, reductions in force (RIFs), accessions, and the like. An interactive simulation model can be used to test the effects of changes in retirement systems and of skill-level constraints imposed by Congress or the OSD. Successive runs are used to determine the best policy—"best" meaning a policy that results in an intuitively desirable force. This simulation process cannot be called optimization, because it can never be guaranteed to reach an optimum. It furnishes an array of acceptable policies, however, from which the planner can choose the one with the best tradeoff of effectiveness and cost.

EVALUATION OF PERSONNEL MODELING

A host of personnel models have been devised; the problem is how to evaluate them and, if possible, their contribution to meeting defense objectives. The answers can be evaluated from two standpoints. Models can be evaluated technically by the quality of the data they use, the realism and reasonableness of their assumptions, the accuracy and applicability of their mathematical algorithms, and so on. This is the approach taken in the methodology developed by NPRDL for its survey. The other approach, which we have adopted for our review, is to evaluate a model's contribution, or potential contribution, to the effectiveness of DoD personnel management. The evaluation stresses the concept underlying the model, the policy recommendations the user derives from the model, and the consistency of these policies with the DoD's objectives in personnel management.

The difference between the two approaches is one of emphasis. This review endorses NPRDL's standards for technical evaluation, which we find both rigorous and reasonable. NPRDL has produced a "model evaluation worksheet" to be used by trained analysts in evaluating specific personnel models. The questions developed for the worksheet are reproduced in App. C of this report.

The evaluation of personnel modeling on a broader scale requires knowledge of the objectives of manpower management and how policies can contribute to or prevent their fulfillment. We assume that the principal objective of defense management in general, and personnel management in particular, is to see that the desired level of defense capability or productivity is achieved at *minimum cost*. But since the personnel manager has control of only manpower resources, his actions involve suboptimization rather than true optimization. The desired level of defense capability is expressed in the foreign policy objectives of the United States and in the missions of the U.S. military; it is reflected more specifically in the size and structure of the military forces.[3] The management of the military force to achieve a specified level of output or capability at minimum cost is referred to in economics as "productive efficiency."

The questions to be answered are: (1) What are the conditions for achieving productive efficiency? (2) What kinds of guidelines do efficiency conditions provide for evaluating military manpower models?

DECENTRALIZED DECISIONMAKING

Although efficiency in defense management implies that policies are chosen to minimize the cost of meeting defense requirements, an overall optimum can sometimes be achieved through a series of independent suboptimizations. That is, managers in different parts of the defense establishment can make independent decisions on the basis of a limited amount of information provided by a centralized authority. The possibilities for decentralized decisionmaking have received considerable attention in the literature of economics and management science through the years. In the classical applications of decentralization, the manager is given a

[3] The cost of defense may be defined in several different ways: current budget costs, accrued budget costs, economic cost to DoD, or social opportunity cost. For most of the models examined here these definitions will be virtually identical.

value for his outputs and "costs" for his inputs. The manager is asked either to maximize the value of his outputs for a given budget or to minimize the costs of his inputs for producing a given level of output. At some level, however, central management must determine the proper level of output or the correct budget for the decentralized authority. In defense manpower, if the manager is given a productivity index and the cost for each kind of manpower input, his achievement of some total productivity index at minimum cost may be consistent with overall defense efficiency.

Decentralized decisionmaking can be very difficult for the military manpower manager. He must choose between military and civilian personnel, between capital and labor, and between other factors affecting the optimal allocation of military manpower resources. Casual evidence suggests that it is difficult to make tradeoffs between various types of compartmentalized resources anywhere in the DoD.

Decentralized decisionmaking can use suboptimization models to produce a proper allocation of resources. Although suboptimization in manpower management does not necessarily lead to inefficiencies, one form of it invariably produces bad policies: the determination of policy on the basis of too narrow a range of policy options. It would be a bad mistake, for example, to use promotion policies alone to determine values for a broad range of other policies, such as retention, accession, and retirement, without consideration of cost, productivity, and other variables. No one in the DoD necessarily acts in this manner, but some of the models developed for grade management are very narrowly constructed. An argument in support of managers who consider a single set of policy variables in isolation, such as promotion policies, is that their authority may extend only over grade management. Nevertheless, although the manager may be blameless, the management function will suffer if manpower and personnel policies are not fully integrated.

MANAGEMENT IN THE CONTEXT OF THE TOTAL FORCE

The allocation of resources within the DoD is considerably more difficult than the simple paradigm of the previous section. Scenarios, missions, major weapon systems—all are subject to heated debate and major disagreement within the defense community. The problem is equally difficult for the manpower manager. Even if total control over manpower resources were vested in one manager or one office in each of the services or in DoD, the manager would have control only over a limited set of resources. Consequently, in acting to minimize the cost of providing a specified defense capability, he is essentially carrying out an exercise in suboptimization because he lacks control over weapon systems and other capital equipment.[4] Moreover, if the "wrong" weapon system is chosen, the manpower manager must adapt his plans to it even if he knows how the force should be optimally structured. If the Navy erred in choosing additional SSBNs over additional CVANs, the manpower manager would have no choice but to augment the personnel required by ballistic missile submarines rather than attack carriers.

Rarely does the manpower manager have effective control over all manpower

[4] Suboptimization is not necessarily bad, of course, as the remainder of this section indicates. Even a manager vested with total responsibility for providing forces to achieve a given level of national defense is acting suboptimally in the sense that the level of national defense is taken as given.

resources: military and civilian, active and reserve. Even more rarely does a manpower model include, on a large scale, both military and civilian personnel or both active personnel and reservists. The modeling exercise that each service has operated in recent years attempts to develop an objective force by grade and length of service. Since at best such models must take civilian and reservists as given, manpower models are more suboptimal than the overall manpower decision. Most manpower models, however, deal with only a small portion of the spectrum of processes affecting defense manpower. Thus, there are models devoted to requirements, accessions, losses, grade management, retention, and assignments.

To the extent that individual processes represent distinct facets of the manpower or personnel system, it is probably sound to construct models along single-process lines. Doing so makes it more difficult, however, to draw policy inferences that are consistent with the fundamental objective of efficiency in defense management. In general, the smaller the piece of the problem analyzed, the more obscure are the policy implications to be derived from the model.

THE NATURE OF THE MANPOWER MODELING PROBLEM

The application of modeling to the military personnel system requires an understanding of some of the system's peculiar features. Most important of all, it is a closed system in that trained, experienced manpower is usually produced within the system rather than recruited from outside, constituting what is essentially a closed labor force.

Personnel enter the force at the most junior grades in the officer and enlisted ranks. The length of time they spend in active military service has a strong bearing on their rank and pay. Opportunities for "lateral entry" of experienced personnel at higher grades are limited in the military to medical doctors, musicians, construction tradesmen, and, intermittently, a few other skills. Consequently, a closed system necessarily has greater continuity and stability in its personnel than does, say, an industrial firm. That advantage has a corresponding drawback: the planning function taken on by personnel managers necessarily is much more crucial, because leaders and other experienced personnel can be produced only within the system. Planning models help insure that sufficient experienced personnel will be available in the future.

A major difference between long-run and short-run manpower management is that a much larger array of policy instruments can be brought to bear in the long term. In the short term the manager must deal with the military force as it exists at the moment. He may make policy changes in promotion, accession, and retention that influence the direction of change for the force, but only with time will they significantly affect the force.

The composite effects of numerous policies determine the future force. Special pay, bonuses, and compensation levels in general are variable and affect the size and composition of the force. Policies such as those governing promotion and grade management affect the grade structure. And the quality of the force is directly affected by policies regarding mental, physical, and performance standards. In the long run, military manpower requirements are also variable, as capital inputs can be substituted for both military and civilian labor inputs. Hence the choice of policy

variables to include in a manpower model depends on the time horizon of the manager who will use the model.

CRITERIA FOR EVALUATING MANPOWER MODELS

We used eight general criteria in our evaluation of DoD manpower and personnel models. We did not rigorously apply them to every model in our review, however; rather, we used them as a basis for our thinking in preparing comments on the individual models.

1. For an optimization model, is the objective of the model consistent with overall efficiency in national defense or in manpower management? In particular, does the objective function include the implications of policies for the cost and productivity of the military force?
2. For the many nonoptimization models, which furnish managers an array of policy choices, does the model in actual use (a) take into account the proper range of variables and (b) reflect objectives consistent with overall efficiency?
3. Is the model correctly placed in the hierarchy of decisionmaking within the service or OSD? Is feedback available from different levels in the hierarchy to evaluate the effects of policies derived from the model—i.e., is this a case where decentralized decisionmaking is expected to function well?
4. Is the model, as formulated, unnecessarily suboptimal in considering only a few of the policy variables available to the manager or in ignoring the most important variables? A model that totally omits cost and productivity from its calculations is clearly incomplete.
5. Does the model adequately represent the behavioral relationships present, particularly behavior that would be affected by policies under consideration in the model?
6. In the use of steady-state models, is consideration given to the dynamic problem of adjusting to the steady state? Are transient conditions derived from the model and does the model user explore the short-run behavior of the system?
7. In cases where the system can be expected to exhibit large random variations—in personnel flows, for instance—or where policies may have uncertain effects, are the model users encouraged to experiment with different values of the suspect parameters?
8. Is the mathematical formulation appropriate for the problem under investigation? This covers a list of questions about the specific formulation of the model. For instance, is long-run steady-state analysis being used to analyze a short-run dynamic problem? In a linear model, are crucial system features lost by ignoring interactions and other nonlinearities? Is the time horizon of the model long enough to indicate the full effects of the policies under investigation?

Chapter 3

THE CURRENT STATE OF THE ART

In conducting this review, we were primarily interested in manpower and personnel models that address high-level policy issues with large-scale implications. The NPRDL compendium [1,2], with its one- or two-page descriptions of each of the 200-plus DoD models, is a useful starting point for anyone interested in surveying the scope of the DoD manpower modeling effort. For our purposes, however, we selected 26; some were included in that Navy survey and others were more recent additions, representative of the assumptions, techniques, and problems of the class of models under consideration.

NONOPTIMIZATION MODELS

The technical term "nonoptimization" means that the model contains no internal operational method by which to reach an optimum, such as maximum productivity or minimum cost, given that requirements or other conditions must be satisfied. In their actual planning role, however, "nonoptimization" models are used iteratively to reach an optimum prescribed by the user's judgment. Insofar as simulation can be used in a management context as a surrogate for experience, these personnel models allow planners to ask "what if" questions and evaluate tentative results before actual policies must be determined. Moreover, by testing and evaluating different policies through successive computer runs, the decision-maker's perspective can be altered by enhancing his sensitivity to the complex way in which policy changes affect the personnel system. Thus, beyond their role in testing individual policy options, simulation models serve usefully in an ongoing heuristic process essential to effective decisionmaking.

Models may or may not embody costing procedures, depending on their role in the planning environment. There may be no need for procedures to cost the aspect of a personnel system; the planner may be analyzing force structures independently of costs or budgetary restrictions. The central concern may be to highlight and expand some major policy in the personnel system, or the analysis may need information to be gained by allowing policies to develop in an unhampered environment; in such cases, the end force produced frequently has no costs computed with it.

Even when costs are supplied, few of the models surveyed produce strictly budgetary projections. Although models with costing procedures may output values for training, procurement, retirement, and total costs for a force profile, these dollar costs—discounted or not—usually appear with the implicit or explicit assumption that they will be used to evaluate alternative force structures. In other words, cost figures are to be used as comparative measures rather than absolute dollars to be allocated for specific missions.

With this brief review of the role of nonoptimization models, we can move on to a more detailed analysis of the state of the art. The following discussion ad-

dresses the most basic question: What is a model and how does it simulate a manpower system?

A MODEL AS A MAPPING

The dictionary defines a model as "a description or analogy used to help visualize something (as an atom) that cannot be directly observed"; the model may consist of "a system of postulates, data, and inferences presented as a mathematical description of an entity or state of affairs." Its structure may consist of variables, functions or relationships between variables, and equations or sets of equations that may or may not be dependent. A model is formed when these structural entities are assigned meanings that correspond to objects, events, or series of events in the real world. In short, a model is a mapping between a set of mathematical entities and the real world.

DENSITY OF MODEL DETAIL

The density or degree of detail in mapping is a rough indication of the model's "realism." Two extremes will illustrate the point. On the one hand, the mapping theoretically could be in a one-to-one correspondence with every detail of the real world relevant to military personnel. Such a model would be a replica of the real world simulated in real time, and would demand a massive, complex, and expensive computer system. (Simulations of complex nuclear reactions that trace nuclear decay, half-lives, and dispersion of nuclear particles fall in this category.) Furthermore, the output of such a simulation would be as complex and difficult to evaluate as the world itself. At the other extreme, the mapping could be all-to-one; the model would assign all mathematical entities to a highly restrictive area of military personnel. Such a model is designed to capture only the essentials of the system, and in the extreme case would simulate only one isolated paradigmatic case. The mathematical structure of such models would be complex, but their data-management requirements would be lessened and, generally, the models would be less expensive to run. Of course, output from a model that simulates paradigmatic cases supplies information too general for the needs of a policy analyst.

Obviously, neither extreme is suitable for policy analysis, but comparing the two yields insights about the kinds of tradeoffs a model builder must make to suit the model to the task. Basically, manpower models are many-to-one correspondences; depending on the purpose of the analysis, the models develop as compromises, falling somewhere on a continuum between the two extremes.

The following section discusses model characteristics and relates them to techniques for dealing with the mapping conditions. These attributes are presented as dichotomies, e.g., predictive versus ideal, entity versus aggregate, actual inventory versus derived distribution. Rather than view these polarities as dimensions in an n-space, the reader should think of them as pointers that locate the position of models along the density continuum. (Accordingly, they are not mutually exclusive characteristics; in fact, presence of one may imply presence of another. For example, a model with a derived distribution usually aggregates, but the converse may not hold because aggregate models can use actual inventories.)

PREDICTIVE VERSUS IDEAL MODELS

Among the models cited in this study, ideal models purposely ignore idiosyncratic elements of a personnel system and concentrate on salient features that affect the total structure. For example, an ideal model would not take account of differences among service branches in initial retirement age, but instead might use an average or typical age. These models provide projections based on hypothetical policies allowed to operate in an idealized environment. Therefore, the outcome of an ideal model derives from a causal chain of events where the interacting elements are limited, well defined, and carried to their logical conclusion. Because it is assumed that the day-to-day variabilities that ideal projection models ignore will eventually be dominated by the important features they do contain, ideal projection models are used for long-term planning.

Whereas ideal projections are necessarily sparse mappings, strictly predictive models are more dense.[1] They try to account for more real-world contingencies and details. Their objective is to produce a snapshot of the personnel structure at some future point in time; consequently, they incorporate more variables and allow them to vary through time. Unfortunately, as the number of variables or characteristics described by a system increases, the more difficult it becomes to capture all the forces that may impinge upon them at future points. Accordingly, the accuracy of the picture diminishes rapidly, and strictly predictive models lose predictive power in the long range. However, they are frequently and effectively used for short-term planning.

ENTITY VERSUS AGGREGATE MODELS

The basic information upon which modeling superstructures are imposed is a force distribution or inventory. As raw data, this basic information consists of personnel records that identify every member of the armed forces by standard data such as sex, rank, age, date of enlistment, service, test scores, zip codes, etc. In organizing this information, model designers have several choices. Some treat each member of this database as an individual entity in the model. Others form groups of database members that have similar characteristics by aggregating them into cells. Accordingly, the former models are called *entity* models, and the latter *aggregate* models.

Naturally, models that simulate and predict individual behavior require greater detail and denser mapping, and treat each member of the database as an entity. Among the entity models surveyed in this paper, each individual's record can be located at any point in the execution of the model, and each record contains from 15 to 43 data variables. If there are 100,000 or more individual records, the detail and complexity of these models are obvious, let alone their data-management problems. Typically, these models require long execution times and trained personnel to supervise data input and model execution.

The aggregate approach groups individuals who share relevant characteristics

[1] "Predictive" is used in this context only to refer to simulation techniques. The term is *not* used in the same sense as a mathematician would use it in referring to statistical techniques, such as regression analysis, where accuracy of the predicted result is quantitatively measured.

into cells. As a result, the detail with which the model can predict behavior is filtered through levels of aggregation and the outcomes are associated with the attributes chosen to identify a cell. Because aggregate models simulate group behavior, they are not strictly predictive. Instead of tracing individual records as entity models do, operations are performed on numbers in cells dimensioned by the attributes in the aggregation set.

The characteristics chosen to aggregate the inventory are critical, because information used in manpower planning may have different effects depending upon the ways in which it is displayed. For example, decisions based on total end strength given by years of service only may be less effective than decisions based on total end strength given by years of service and grade. While the years of service distribution alone may appear optimal, it is possible that years of service distributed over grades will reveal bottlenecks or lags that will cause shortages or surpluses in future years. (This consideration is especially important in retirement studies.) Most of the nonoptimization models we surveyed exhibit attributes in the form of a grade-by-length-of-service array. However, depending upon the policies analyzed and the limitations imposed, attributes may include source of commission, end of obligated service, date of rank, component (reserve or regular), military occupation, year of enlistment (cohort), etc.

Generally, aggregating the basic inventory information minimizes data management problems and reduces execution times. However, certain characteristics of members of the force have been deemed more important than others in the selection of aggregation attributes. As a result, the models have moved one step away from the strictly predictive, denser-mapped extremes of the spectrum demarcated by the fundamental mapping condition.

ACTUAL INVENTORY VERSUS DERIVED DISTRIBUTIONS MODELS

Selection between the entity versus the aggregate modeling technique is an incremented change, however, because aggregate models may still be considered predictive if their data or basic information display derives from an existing inventory. In this case, numbers distributed among the aggregation set are computed by tallying master personnel files. Aggregate models become ideal projections only when the distribution of personnel among the aggregation set is analytically derived rather than empirically computed. At this point, a distinction is made between two classic manpower modeling techniques for describing the basic information display: an actual inventory and a derived steady-state distribution. Although several techniques are available to create steady-state distributions (see "Steady-State Versus Dynamic Models," below), a necessary condition is common to all. It is assumed that an equilibrium condition exists, that the total number affected by policies entering a given cell is equal to the total number affected by policies leaving a given cell. It follows from this condition that models using a steady-state distribution are time-invariant, while models using an actual inventory may allow numbers in a particular cell to vary through time. Obviously, models with steady-state distributions approach the idealized extreme of the manpower modeling spectrum, while actual inventory models fall closer to the predictive end.

Once an actual inventory or derived distribution of the force is created, real-world happenings can be simulated. In modeling terminology, these processes are called *laws of motion*. These laws describe the ways in which movement can take place to drive the initial information display to a terminal point on the planning horizon. Interim stages in this process are called *states*. In manpower models, laws of motion correspond to policies on promotion, attrition, accessions, augmentation, suspension, etc. These policies, in turn, take the form of rates that can be derived from historical or empirical data, or they can be supplied by the analyst. For example, losses to the force through nondisability retirement, end of obligated service, or desertion may be based on data collected from past years. Occasionally, loss rates are not simply drawn from historical cases. Some ancillary mathematical techniques may be employed to "smooth" the data, or another special purpose statistical model may be employed to derive, from empirical observations, rates that will better predict losses. If the rates corresponding to policies do not have an empirical base, they fall into a special category. These *decision variables* are another important design feature of the model because they instantiate the decisions of manpower planners that can affect the course of future events. Most models emphasize a particular policy; usually this emphasis can be determined by the number of decision variables designed into the model relevant to that policy. Examples of analyst-supplied values are continuation, training, procurement, and promotion rates.

DETERMINISTIC VERSUS STOCHASTIC MODELS

Application of these rates results in the movement from state to state characterized as a law of motion. The facility for this procedure is to house these empirical data and decision variables as rates in an array (matrix) indexed by all the attributes or individual characteristics relevant to the policy under consideration. To select an individual record or to compute the numbers that will move to a next state, the rates are multiplied by the number in a cell. A simplified mathematical description of this movement is

$$X_{i+o} = R \times X_i$$

where X is the number in a state, R is a transition matrix, and i is a state denoting index. Straightforward application of these rates is a *deterministic process*, a Markovian transition insofar as movement to the next state is determined by presence in the current state. Occasionally, selection for movement does not follow the application of rates procedure described above. In certain cases, individuals or numbers may be selected randomly, and the model then contains a *stochastic* process.

Exhibited in this facet of laws of motion is another classifying attribute of manpower models that illustrates a further limitation imposed by the fundamental mapping condition. Both predictive and ideal models can have deterministic processes. As a rule, deterministic processes predominate in ideal models because the laws of motion are limited and well-defined operations on an analytically derived distribution. Stochastic processes most often appear in predictive models because reliance on random choice occurs when the causal links break down and the multi-

plicity of variables results in an unclear selection rule. Use of random numbers, then, accounts for variability in real-world events that is beyond the purview of the model's definition and structure. Because of the detail and closeness of mapping required, this condition most frequently occurs in predictive models.

Two examples from the models surveyed illustrate *stochastic processes.* The first is referred to as an integer problem. Because the numbers in a cell are allowed to vary through time, it may occur that the number remaining in a cell is less than a whole man or integer. In that case a random number generator may be used instead of rates to determine if all or none of the cell moves to the next state. In the second example, the model is forced to simulate events on a statistical level. Typically, this method is used to simulate meetings of promotion boards that choose eligibles for promotion, or to select losses.

Limitations are also imposed upon laws of motion. The real world inhibits the flow of these movements by rules, regulations, and feasibility considerations. To map restrictions on policies, models usually contain *constraints* that set boundaries on final configurations of the force at the end point. These constraints may consist of end strength requirements, grade requirements, limitations on age or years of service (retirement), lower bounds on critical manning levels to assure preparedness, Congressional directives, notions of equal treatment, and budgeting limits.

In general, the conceptual framework we have outlined thus far classifies models as ideal versus predictive, entity versus aggregate, and deterministic versus stochastic. The basic information operated upon in the modeling process was described as an actual inventory versus derived distribution. An extended classification of this distinction is dynamic versus steady-state models. Table 3.1 summarizes the expanded characteristics of this traditional differentiation in models, and the following section explains how the preceding characteristics fit into the more general steady-state versus dynamic categorization.

Table 3.1

COMPARISON OF DYNAMIC AND STEADY-STATE MODELS

Model Component	Dynamic	Steady-State
"Main array"	Current inventory	Distribution of force
Laws of motion	Procurement, attrition, promotion	Procurement, attrition, promotion
State conditions	Cell size varies with time	Flow entering cell equals flow leaving cell
Output	Projected distribution	"Ideal" distribution of end strength

STEADY-STATE VERSUS DYNAMIC MODELS

The previous section has developed model characteristics didactically. The approach was to postulate a fundamental mapping condition and present modeling techniques as ways of dealing with the mapping concept. These characteristics can be used to define two more general categories of models, dynamic and steady-state.

The basis for this extended classification is choice between an actual inventory and a derived distribution. Dynamic models work with actual inventories; steady-

state models work with analytically derived distributions. Dynamic models more closely approach one-to-one correspondence mapping, and hence are more predictive as a class than steady-state models, which deal hypothetically with restricted, essential aspects of the personnel system.

Steady-state models aggregate their distributions and the laws of motion work deterministically, usually as embedded Markovian processes. A wider range is evident in dynamic models, where the actual inventory may consist of entities or aggregated groups. Dynamic laws of motion exhibit both deterministic and stochastic behavior.

When used as devices for idealized projection, steady-state models are employed in long-term planning. Their typical planning horizon is twenty years. Dynamic models, on the other hand, project the force anywhere from one month to ten years into the future; thus, they serve short-term planning needs that call for detailed and accurate information.

The distinction between the two can be seen more sharply by examining their actual structure as it is realized in the interaction between the basic information display—an actual inventory or a steady-state distribution—and the laws of motion. One should also consider their methods for parameterizing decision variables, and the ways in which policies drive the laws of motion. Accordingly, although individual models exhibit individual approaches in their parameterization and mathematical techniques, we generalize below the basic techniques found in the two kinds of models and discuss their uses and limitations in the planning environment.

Steady-State Models

Two conditions make steady-state distributions feasible. First is the assumption of equilibrium: that the total number affected by policies entering a state is equal to the total leaving the state. Second, military personnel systems are closed systems, with virtually no lateral entry. Because of these conditions, at least two distinct kinds of steady-state models are possible: backward models that begin at the system's sink, and forward models that begin at the system's source. The terms "backward" and "forward" describe the direction of flow; "source" and "sink" describe system entry and exit points.

Both kinds of models embody sets of equations. Each equation of a given set defines the law of motion for a particular year of service and the whole set defines the laws of motion for a grade containing those defined years of service. The initial problem to be solved by these two approaches, then, is to distribute total force numbers into these grades by years-of-service sets.

One approach is to create a distribution over years of service alone and then to break the distribution into grades. Obviously, a total strength value is needed. Next, a set of retention rates is input, and the product of these rates is taken to compute survival rates for a given year of service. These survival rates are summed to compute an average career length which, in turn, divides the total force strength to calculate the number of procurements. The distribution of personnel over years of service follows by successively applying retention rates to the number remaining from the previous year (procurement in the first year). To spread this years-of-service distribution into grades, a promotion-related variable must be input. These

values are usually probabilities of moving into the next grade (or higher) given a particular year of service and given that an individual is in his or her present grade. Applying these values to the total numbers in a given year of service produces the needed solution. So, with total end strength, a set of retention rates, and promotion probabilities, a steady-state distribution can be derived. Because this procedure is ultimately working with procurements (source), it would properly be used in a forward model.

To use identifying characteristics in addition to years of service and grade, aggregate forward models form substructures by taking different combinations of attributes in an aggregation set, so that retention rates may be given by source of commission, or different distributions over grades may be formed for different procurement sources. The applicable rates corresponding to different policies are then used within substructures to move the force from state to state. The final step in any substructuring technique is to sum the numbers within the substructure to calculate total end force.

Backward models take an entirely different approach. Although the equations are similarly defined by years of service and grade, the critical known value is the number moving out (promoted out, retired, attrited) of the last state (sink). Because steady-state conditions hold, it is then possible to compute the number who move into that state. Following this procedure recursively, it is possible to arrive at the number of procurements necessary to support a given force strength level.

As a rule, backward models are more flexible than forward models in parametric analysis because they can set certain parameters, such as total number in a grade, and solve for others, such as promotion probabilities. In fact, backward models can produce an output that would normally be input to forward models. However, backward models have less capability in working with different attributes in the aggregative set. Accordingly, emphasis must be put on input which, as a result, is occasionally complicated, preprocessed by another model, and/or specifically tailored to the planning problem under consideration.

The structure of these models constrains their utility for planning. In the first place, models are usually designed to simulate either the officer force or the enlisted force. This separation is implicit in the division between grade management and career field management. Steady-state models that emphasize decision variables related to promotion are generally used to study officer force structures, because the supply of more experienced supervisory personnel comes from lower grades. Since the military has no lateral entry, the main way to control this supply and distribution is through promotion policies. The other facet of this supply and distribution problem is retention behavior. Forward models that allow retention (or losses) to be set by the different attributes in the aggregation set allow the planner more ways to interface his decision variables with the more complex behavior categorized as retention, an area of current interest and ongoing research.

Models of the enlisted force place less emphasis on promotion policies and more emphasis on distributions of the force in military occupations and skill levels within these occupations. The key issue is then to define decision variables to influence the grade and years-of-service distributions within a military occupation or groups of military occupations. Flexibility in defining the levels of aggregation is a desirable design characteristic in career field management models; a model may have occupational group as a dimension, or the whole model may be dedicated to analyzing a particular career field. Training rates are also more important in these models.

Retention behavior is clearly a common issue for both the officer and enlisted forces. Current research in manpower modeling is actively interested in the ability to determine accurate retention rates and to predict retention behavior. The importance of that ability is highlighted under "Dynamic Models" below, because while in steady-state models the role of driving the simulation system is shared by promotion-related variables, losses are most important in dynamic models.

Dynamic Models

The major factor in dynamic models is treatment of attrition or, viewed another way, retention. Because the military is a closed system, losses affect promotion and procurement either directly or indirectly.

The ways in which losses drive the system are constrained by the beginning inventory and end strength requirements that must be satisfied. Given these constraints, dynamic models follow a basic procedure: The loss rates are applied to an actual inventory to produce a residual inventory, which in turn is compared with a set of requirements to determine the number of vacancies available. The vacancies will be filled by promotions and accessions. The order in which these policies are computed is determined by the kind of requirements given. For example, if the end requirements are stated in terms of grade, promotions are performed first, followed by accessions. But if end requirements are given by critical manning levels in an occupational specialty, accessions would be computed first, to be followed by promotions. After all policies have been simulated or movement from cell to cell has taken place for a given inventory, the whole force is aged one time period. The procedure is then repeated until a predetermined planning horizon has been reached.

This pattern is open to wide variation, especially in the ways losses are defined and treated. For example, the models surveyed recognize from 3 to 25 different causes of loss. Loss causes can also be differentiated by military occupation. Some models have algorithms to convert yearly loss rates into monthly loss rates, taking into account seasonal variations. Others use special purpose models based on statistical techniques such as regression analysis or the Automatic Interactive Detector[2] to generate loss rates. In some cases, loss causes can be treated as decision variables; values are supplied by the analyst and automatically constrained by other policies, or the analyst can alter values for specific loss causes in specific years of the dynamic projection.

Although not nearly as important as losses in driving the dynamic system, promotion policies are simulated in equally sophisticated ways. For example, promotion may require predicting the number that will pass qualifying examinations or creating the distribution and selection of eligibles among promotion zones and at promotion phase points. Signaling eligibles for promotion may require tagging the inventory randomly as a result of the meeting of promotion boards; or predicting promotion may require using regression analysis or EOR (supervisory ratings) means on individuals in the inventory.

[2] A statistical technique developed by John A. Sonquist and James N. Morgan at the Institute of Social Research, University of Michigan, in 1969.

Conclusions

The foregoing discussion embodies three major conclusions. First, both dynamic and steady-state models exhibit sophisticated, although limited, capabilities in simulating military manpower systems. The limitations arise from at least two sources: (1) Few, if any, exogenous variables are allowed. For example, these models do not systematically account for the effect of the state of the economy on accessions, or the effect of civilian wage rates on retention. (2) The behavioral assumptions are sparse. Such notions as perceived pay and the feedback effects on retention as people approach retirement or receive bonuses may be implicit in empirical retention rates, but no design feature explicitly accounts for these motivations in the simulation models surveyed. We suggest that future large-scale manpower models would be more useful for planning if these other kinds of variables were parameterized as decision variables.

Second, the conceptual framework we have presented classifies models along a density continuum using characteristics, some of which may subsume others, as indicators toward either the predictive or ideal extremes. While these characteristics are not mutually exclusive, they can be usefully applied in comparing and contrasting the objectives, techniques, and design of nonoptimization manpower models. Table 3.2 lists models surveyed with these characteristics.

Third, the purpose of these models is to support the discretion of manpower planners, not replace it. Short-term planning models (dynamic, aggregate or entity) give a fairly accurate, immediate picture of the near future; long-term models (ideal steady-state projections) illustrate the ultimate consequences of initiating policies under controlled conditions. No model fully satisfies every planning need, but models are instrumental to an ongoing heuristic process that allows planners to test and evaluate the effects of their decisions in the selected ways that mappings of the real world permit.

OPTIMIZATION MODELS

Several recently developed DoD models can be called large-scale optimization models. They include the six surveyed in this report: the Bureau of Naval Personnel's work to develop the ADSTAP system [17], the Office of Civilian Manpower Management (Navy) series of OCMM models [18], the Army's contract to develop an Enlisted Objective Force Model [19], Rand's effort under ARPA sponsorship on optimal military pay [20], preliminary work on an Enlisted Personnel Projection and Simulation Model conducted at CNA [21], and finally, ONR-funded research by the Operations Research Center, University of California, Berkeley, on longitudinal manpower models [22].

Builders of optimization models tend to add costing, objectives, constraints, and decision systems to basic flow description models. Optimization methodology uses systematic procedures to find a best set of decisions (called the best policy) that satisfies constraints. In some cases, mathematical analysis indicates that no other set of policies produces a better solution, whereupon the model is said to have found the optimal policy.

Computational necessity forces most optimization models to use simpler basic

Table 3.2

MODELS AND CHARACTERISTICS OF MODELS SURVEYED

Model	Agency/Developer	Characteristics
AID-E (Enlisted) AID-O (Officers) (Automatic Interaction Detector Loss Probability System)	Army/GE TEMPO	Predictive, entity, statistical loss-rate models for the enlisted and officer force.
COFPM (Constrained Officer Force Projection Model)	USAF/Rand	Ideal, aggregate, deterministic, steady-state, forward, grade management.
CIM-E (Enlisted (Central Integrating Model)	Army/GE TEMPO	Predictive, aggregate, deterministic, dynamic, career field management, costs.
CIM-O (Officers) (Central Integrating Model)	Army/GE TEMPO	Predictive, entity, stochastic, dynamic, career field management.
DEMOS[a] (Defense Enlisted Management Objectives Simulation	OSD-M&RA/various Hq USAF, Army, USMC	Ideal, aggregate, deterministic, steady-state, backward, career field/grade management, costs.
DOPMS (Defense Officer Personnel Management System)	OSD/M&RA	Ideal, aggregate, deterministic, steady-state, forward, grade management.
DOPMS	USAF/Hq USAF-Rand[b]	Predictive, aggregate, stochastic, dynamic, grade management, costs.
FAST (Force Analysis Simulation Subsystem of MAD-O, Adstap System)	Nacy/NPRDC	Predictive, aggregate, deterministic, dynamic, career field management.
NRETIRE (Retirement Section of DYNPCM: Dynamic Personnel Costing Model)	OSD-M&RA	Predictive, aggregate, deterministic, dynamic, retirement costing model.
OGIMOD (Officer Grade Limitation Model)	USAF/Rand	Ideal, aggregate, steady-state, backward, grade management.
OPM (Officer Projection Model)	Navy/CNA	Predictive, aggregate, deterministic, dynamic, grade management costs.
OSSM Models (Officer Structure Simulation Model) a. AFSC Analyzer b. Aggregate Model c. Entity	USAF/AFMPC	Ideal, aggregate, deterministic, dynamic, career field management costs. Predictive, entity, stochastic, dynamic, career field management.

Table 3.2 (Continued)

Model	Agency/Developer	Characteristics
TOPLINE DYNAMIC (Total Officer Personnel Objective Structure for the Line Officer Force)	USAF/Hq USAF	Ideal, aggregate, deterministic, dynamic, grade management.
TOPLINE STATIC	USAF/Hq USAF (Rand)	Ideal, aggregate, deterministic, steady-state, forward, grade management.

[a]This model has wide application throughout the services. It is variously referred to as "The Airman Steady-State Model," two versions of which are used in the multimodel Air Force Enlisted Management System: (Army/DoD modification of the original Air Force model).

[b]Rand developed the costing routines.

[c]Rand modified the original Hq USAF model.

descriptive models than are found in nonoptimization models. One will find there no detailed descriptions of the state of the system, such as the number of men by grade, length of service, and skill level or category. Optimization models must examine manpower aggregated by length-of-service designations.

Several mathematical models are interwoven to produce an optimization manpower planning model. The fundamental flow process is described by a basic model of the law of motion. A decision model is set up to represent the effect of changing policy on this flow process. Reductions in force (RIFs), promotions, accessions, and bonuses are real-life policies that must be modeled. A costing system to predict costs as well as manpower flows is added. Real-life constraints, such as requirements, grade limitations, and total force limits, become part of optimization models by constraining the feasible set of policies available.

Categories of Optimization Models

We have chosen to develop categories for the six models based on the different optimization methodologies used: goal programming, force suboptimization, and force efficiency. The model structure individually developed by model builders virtually dictates the methodology that can be used.

Table 3.3 lists these optimization models by category, subject, and sponsor.

Suboptimization Models

Suboptimization models address the setting of policy in a decentralized environment. The objectives are not global, but are those of the smaller organizations making up the entire military. The objectives and policy at this level are handed

Table 3.3

DoD MANPOWER OPTIMIZATION MODELS

Type of Model	Subject	Origi-nation	Developer
Goal programming	Civilian manpower (OCMM)	Navy	Office of Civilian Manpower Management
	Enlisted manpower	CNA	CNA
	SRB Enlisted	Army	Systems Automation Corporation
Force suboptimization	Accession requirements, COPLAN	Navy	University of California (Berkeley)
Force efficiency	Enlisted optimization	Rand	Rand
	MAP— (ADSTAP)	Navy	Bureau of Personnel Research

down from higher authority. Models addressing policy at this level can be used quite properly in this multidivisional system if the global optimization is decomposed into properly conceived suboptimizations.

Virtually every manpower model used in force planning is some form of suboptimization model. One organization's objectives and operating constraints are influenced by policies laid down by the head organization. Even the models listed here as "force efficiency" models are suboptimization models. The "best" base commanders' policies are determined as those that are best within the objectives and constraints set by major commands. The major commands are themselves subject to similar guidelines from headquarters at the Pentagon.

COPLAN (Cohort Planning Model) was developed for the Navy. The philosophy underlying this manpower flow model takes an unusual approach. Most models examine the age distribution of the current force and project it into the future using a Markov transition analysis that predicts retention based on past behavior of men with the same demographic characteristics, principally length of service. These cross-sectional models fail to consider the unique character of individual cohorts. Longitudinal models like COPLAN are able to forecast by following and predicting the behavior of single cohorts—personnel entering the service in the same year. It does so by having two explanatory variables to predict retention: length of service (LOS) and cohort. This can improve the predictive accuracy of the underlying flow model, but at the expense of heavier computational and data requirements.

The descriptive flow model, accessions costs, total manpower requirements, and the initial starting conditions are given as inputs. Various optimization techniques, including linear programming in the simplest cases, are used to find an accession policy over a period of years that will minimize the present worth of discounted

accessions costs while meeting the total staffing requirement over each of the years. Because it examines only a small part of the total cost and ranges of policy affecting military accessions and accessions costs, the COPLAN model is a force suboptimization model. Currently, the model is being used in experimentation by Navy planners and is available on the computer system in an interactive mode.

Goal Programming

Goal programming models are characterized by a set of operational requirements constraints that, while individually feasible, are impossible to meet in total. The problem is "infeasible" in the sense that no manpower policy can be found to meet all these objectives simultaneously. Penalty weights are assigned to deviations from a subset of soft constraints and the total sum of these penalties is minimized subject to the remaining set of hard constraints. For several years, the Office of Civilian Manpower Management has been developing goal programming for managing the Navy's civilian labor force. This development has been conducted by Charnes, Cooper, and Niehaus.

A Markov chain transition matrix is used to predict the flow of people between civilian GS levels, between broad skill classes, and out of the system. Decisions are to be made on RIFs from each of the state space categories and fires in each period over an intermediate planning horizon. Real costs, operating constraints on staffing requirements, and penalty costs for deviations from constraints contribute to an objective function to be minimized. Linear equations and constraints and a linear objective function make up the simpler of the models where solutions can be found by using linear programming codes.

The OCMM series of models are being used currently in civilian manpower planning. Both interactive computer terminal input or batch processing mode models of the Navy's civilian work force are in operation.

The most ambitious application of goal programming to a strictly military personnel problem is the model being developed for the Army by Systems Automation Corporation. The model is to be used as an adjunct to the setting of reenlistment bonuses in the Army by determining reenlistment objectives for every military occupational specialty. The value of the goal is a weighted average of three factors: deviation from manpower requirements, deviation from "desired" promotion policies, and the costs of manpower. The model is undergoing testing and development but is not yet in operation.

Input to the model is the "objective force" as determined by simulation runs of the nonoptimization models. On the other side, input of the actual force as projected by other nonoptimization models is made. Accessions and reenlistment objectives in the form of goal programming constraints are obtained by comparing these two forces. Goal programming is used to provide a means of balancing the deviations from constraints with true economic costs of the various policies.

Besides the size and expense of running goal programming computer programs, goal programming is limited by the arbitrariness of assigning goals and of applying penalty weights to deviations from these goals. What is to determine "desired" promotion policies, for instance, and the true cost of not realizing them? Nevertheless, the fact that goal programming can be misapplied is no true argument against it. If there is a basis for setting goals and assigning costs, then goal programming

can be a powerful and useful technique, as Charnes, Cooper, and Niehaus have demonstrated in civilian manpower management.

An Enlisted Personnel Projection and Simulation Model, EPPSM, was developed at the Center for Naval Analyses. The flow of personnel is described by a longitudinal transition model characterizing the force by length of service and entering cohort. Linear equations result from a deterministic view of such models. These equations are the state space relationships of the law of motion. Effectiveness, a concept related to military productivity, is assumed to be a simple linear function of the force differentiated by length of service.

Over a finite planning horizon, a variety of policy decisions are contemplated as variables. Because the model has only been designed, not completely built and certainly not tested, it is impossible to guess exactly what decision variables are planned. Since development of the model has stopped, it is unlikely that we can expect any complete model.

The EPPSM model resembles COPLAN in using longitudinal flow to characterize the manpower system. The manpower constraint takes the form of a linear production function that encompasses, for instance, the simple total strength used in COPLAN. The costing system design was not completed at the time of our survey, but would include retirement, training, and generally a complete range of manpower costs. The exact decision options to be chosen were not decided upon but force composition was the resultant variable. Computationally, the optimization methodology was thought to be goal programming. We chose to include the EPPSM even though it is relatively incomplete, because it is one of the few optimization attempts within DoD manpower modeling.

Force Efficiency Models

Force efficiency models examine the global manpower/personnel policy with the objective of efficient manpower utilization. Usually, only one form of policy variable can be considered because of practical limitations. Such models find use in setting the global constraints and prices to be used in the divisions for decentralized decisionmaking.

Two models, the MAD-P system within ADSTAP and the Rand model on optimal enlisted force composition, are grouped together as force efficiency models. The EPPSM model of CNA is also concerned with overall force efficiency. ADSTAP is a large and ambitious enlisted management modeling system that contains a number of models. One subsystem called MAD-P, consisting of four models, is of interest in this review of optimization models. It can be used to determine optimal steady-state force composition by LOS and grade on a specialty by specialty basis. One of the four MAD-P models is ASTATIC, a steady-state projection model that uses an imbedded Markov process to describe the flow of manpower. The inputs to ASTATIC consist of loss, attrition and reenlistment behavior, promotion policies, and a force size limitation that can apply to the enlisted Navy or to a particular specialty. The output is a distribution of personnel by length of service and pay grade. The second MAD-P model, called the Elasticity Dependency Model, is a manpower supply model that relates retention behavior in a rating to the amount of the first-term and the second-term reenlistment bonus. The relationship between the level of military compensation and the proportion of men reenlisting is a type of reenlistment supply function. This model can also estimate the costs of a reduction

in force (RIF), which might be thought of in terms of the separation pay penalties. The third MAD-P model is a manpower costing model that gives the cost of a given configuration.

The fourth is a utility model that assigns a level of utility derived from having a person with a given length of service and a particular pay grade. The utility levels were the outcomes of a Delphi experiment, in which Naval officers were queried on the utility of personnel in a given paygrade with different lengths of service [23].

The MAD-P optimization algorithm determines the optimal distribution of personnel by grade and length of service by finding the force that is consistent with the minimum cost per utile while meeting various operating constraints on manpower requirements. It is linked with the four models mentioned to determine such policies as those on bonuses, loss and retention rates, and enlistment rates for a specialty (rating) in the Navy. The system is undergoing continual development and present versions are in current use in planning the Navy's enlisted force.

The Rand model features a broad level of aggregation and addresses an abstract or theoretical (as opposed to directly practicable) manpower management policy. This research effort has produced a manpower model that attempts to find the best composition of the military enlisted force in the long run or steady state. It is designed to find a wage schedule and resulting force composition that maximizes steady-state productivity for a given military manpower budget. Thus, rather than analyze bonuses per se, the model considers, as a variable, the entire military pay system including retirement. This objective is closely related to the economic concept of productive efficiency, which would imply a policy with the maximum output for a given cost, or, alternatively, the minimum cost of producing a given rate of output. The model treats military compensation, and thus the resulting rate of enlistment and reenlistment, as variables. Enlistment and reenlistment rates are directly linked to military compensation in the model through manpower supply functions.

This model seeks to determine the optimal composition of the military enlisted force aggregated by term of service. The optimal force is defined as that force which provides the greatest military capability for a given budget cost. Productivity is a function of the force composition used to represent overall military effectiveness. Since individual military personnel differ in both productivity and wage rates, differences in force composition affect both military capability and manpower costs. Pay grades are not explicitly identified within the model; consequently, promotion policies cannot be evaluated. Rather, the model was developed to explore the implications of different military supply functions and productivity measures for the optimal steady-state force structure.

A steady-state model of the flow of personnel through the terms of service is constructed. An optimization model chooses military compensation levels that yield the optimal size and composition of the force. An operations research technique called gradient search, a type of nonlinear programming using a computer-based algorithm, is used to find the solution to the problem.

Expansion of the model is under way to include the dynamic or time-dependent force composition. The steady-state version was completed, tested, and then used for illustrative purposes to demonstrate the applicability of such models and basic assumptions in military manpower planning.

Current Model Roles in Decisionmaking

The 26 models we have examined, and their close relatives, are useful in directly addressing a number of issues. These are usually the most visible and crucial policy issues, such as those governing promotion rates, accession or attrition rates, retirement systems, and retention rates. Nonoptimization models can be used to test the effects of such policies on the output measures of length of service, grade, and skill-level force distribution. If needed, other outputs in the form of costs or military occupational specialty breakdowns are also usually available. Optimization models focus on one or at most two policy variables and optimize some function of the LOS distributions or costs subject to operational readiness requirements.

A variety of indirect issues have arisen in developing and testing these models. One is the importance of productivity measurement of military effectiveness. Most model builders have not appreciated the delicate relationship between requirements constraints and implied productivity. While including firm constraints on requirements, modelers too often implicitly make a productivity assumption that is unrealistically rigid. In the hierarchy of decisionmaking the model plays an important role in setting all types of constraints such as this. This list of indirect issues includes retention behavior as a function of manpower policy and other outside factors, and the effects of the retirement system on retention.

Use of Models in the Decisionmaking Process

We sought to answer four important questions about DoD manpower modeling: Are models actually applied to manpower management in DoD? Are the models useful to managers and decisionmakers? Are the results actually used? Do manpower models contribute to the efficient management of military manpower?

The answers to the first three questions are clear. DoD manpower models exist; they are operated by government offices; and the results are used, particularly in grade management. In fact, the official personnel plans of the Army, Navy, and Air Force are the outcomes—in some cases, the actual computer output—of models. But these simple answers are somewhat misleading. Most of the models used are nonoptimization models of the TOPLINE variety [24], although the Navy is beginning to use the ADSTAP system and COPLAN and the Army is experimenting with the SAC Objective Force Model. In a typical application models are run iteratively hundreds of times, incorporating different sets of assumptions and simulating the effects of alternative policies. The model user then exercises his judgment in selecting the one plan or policy to be implemented. Because of this method of operation, it would be stretching a point to say that models determine policy. In a sense models may be only computational aids, but they really have much more potential value than that. Models serve as an educational tool; they help managers to understand the essential characteristics governing the functioning of the military personnel system. Through a trial-and-error process model users learn about infeasibilities and tradeoffs among different types of policies. Thus, managers are able to develop an intuitive feel for the system prior to exercising judgment.

As we have noted, not much operational experience has accumulated with optimization models in the manpower environment. It seems unlikely that they will greatly simplify the decisionmaking process or replace the judgment of managers. For one thing, the model user ordinarily has a wide latitude of choice among model

specifications and can make multiple runs that produce different outputs. Moreover, it seems highly unlikely that the manager will treat a model as a black box, automatically accepting the output as valid, as one might do with a radar set or an inertial navigation platform. More likely he will, as he should, try to square the outcome with his intuitive judgment; if he cannot, he will probably raise questions about the model's logic and assumptions and about the appropriateness of its answers to the question at hand. This does not mean, of course, that optimization models are unlikely to be valuable. They will be. Occasionally, too, they are sure to produce novel or unexpected suggestions that might otherwise never occur to decisionmakers.

As for the final question, it is too early to say definitively whether manpower models contribute to efficient manpower management in the DoD. Clearly, however, they hold great promise for doing so by improving human decisionmaking, as models have already done in such areas as inventory control, queueing, production scheduling and planning, and logistics. As yet, however, manpower models cannot truly be said to have contributed to efficient manpower management. In the one area in which they have been most heavily applied—grade management—the recommended policies for promotion and retention seem to be distinctly suboptimal. The military services have indicated their intention to rely more heavily on inexperienced personnel and thereby accelerate promotion rates in the career force. This seems to be a dubious stratagem, judging from both intuition and the results of the Rand enlisted force model; it apparently fails to recognize that, with the advent of the all-volunteer force, inexperienced personnel have become more expensive than they once were and the supply is less predictable. This is no more than an educated guess, however, and does not negate either the potential worth of manpower models or the real progress the DoD has made in applying them.

It is clearly desirable that the DoD continue its manpower modeling effort in optimization. Even though few of its models have attained any regular usage (many are still incomplete and unusable), they have directed the thinking of model builders toward the interactions, key constraints, and objectives in the operating system. The need for further analysis of these components and the need for specific new research on productivity and labor supply are evident. Thus far, in sum, the primary benefit to the DoD from optimization manpower models has been educational.

Limitations of Current Optimization Models

Because the DoD's optimization models vary widely in their assumptions, techniques, quality, and practicality, it is difficult to arrive at comparative judgments. For the time being, one is largely confined to commenting on the advisability of each model's purpose, its success, and its omissions and errors. All models, however, idealize and simplify real processes and therefore encounter similar statistical and validation difficulties. The optimization models considered here are still being developed or have not advanced enough for validation experiments to be conducted.

All optimization models except the Rand enlisted force model are intended for implementation within some branch of the service. They embody operational constraints of the day-to-day manpower system. Variations within the existing system, such as accessions, variable reenlistment bonuses (VRBs) RIFs, etc., are the policy variables. In systems subject to large numbers of constraints, such as the military

manpower system, no feasible policy is likely to be found that will satisfy all constraints. We believe it is important to evaluate the effects of these operational constraints to see what a freely operating system would be like and estimate what these constraints cost in terms of lost dollars or productivity.

The fewer constraints in a model, the easier it is to verify and validate the model's predictive ability; but if it appears necessary to add artificial constraints to a model to make it realistic, the model should be revised or discarded. The authors of the ADSTAP report note the danger of adding constraints for that reason. At the other extreme, if operational constraints are so numerous and so structured as to preclude all or most feasible solutions, no true optimization of objectives can be made. Goal programming is used in three of the surveyed models to find a rational way of violating these goals and so achieve some sort of nearly feasible policy.

The Army's OFM model on the use of the selective reenlistment bonus to achieve the objective enlisted force is similar to the goal programming used by Niehaus for the Navy's Office of Civilian Manpower Management. The basic approach is clearly a suboptimization within the larger-scale manpower system. Manpower requirements over the time horizon are specified intuitively in a decision hierarchy above the modeled system, and hire-and-fire policy decisions are made to meet these constraints as closely as possible, with some loss function penalizing deviations from requirements. Real-cost estimates of hiring and firing are estimated and help to avoid frequent personnel changes. Since there is no way as yet to evaluate the true monetary costs of failure to meet requirements, the combined "goal" is still a subjective measure of performance.

Goal programming models can be extremely useful decision aids for department managers at an intermediate level when higher authority has dictated requirements and/or penalty costs. However, these models fail to address what we regard as two of the most important issues in manpower planning. One is the ability to determine requirements and assess military productivity under changing force budgets and manpower size. The other is military manpower supply.

The Rand enlisted force model, which was designed by two of the authors of this survey, differs from the other models in that it was developed to answer some general questions about the optimal long-term structure of the force and not to serve as an on-line, operational guide to current policies. This model, or an expanded version of it, can be used to test major policy changes affecting the retirement vesting system, first-term length, and Congressional manpower constraints, and thus lend support to arguments for adopting these changes. The model evaluates the long-run force and varies compensation to achieve maximum force productivity. It should not be used in its present form for short-term manpower policy. The research stresses the importance of measurement of military productivity to be used in place of standard requirements and the importance of variable enlistment and reenlistment behavior as a function of decisions on retirement, compensation, etc. Before manpower planning models of this type can be used to help high-level policy planners, research into these relationships, which are fundamental constituents of a true optimization model, must be conducted.

The ADSTAP system of models approaches the ideal objectives of optimization models set forth earlier and in Chap. 4 below. Productivity is measured using a linear production function with parameters from a series of Delphi questionnaires.

Cost is made a function of retention or continuance rates as determined in the model based on deviations from historical norms. Significant effort has been made to estimate real parameters and make the system operational, although there are substantial empirical problems in the estimates made. The measure of performance currently in use (cost per utile of productivity) is not the fundamentally correct measure of performance and requires an added structure of supports in terms of requirement-type constraints to avoid reaching trivial solutions. While this problem cannot be easily overcome, the system of supporting models within ADSTAP and MAD-P can remain unchanged when a new objective function and revised method for estimating productivity are devised. Chapters 5 and 6 contain a complete discussion of the problems in using the ratio of cost to utiles as an objective, and supplementary material appears in the appendix.

The Enlisted Personnel Projection and Simulation Model developed at CNA has also addressed productivity and manpower supply through variable enlistment and reenlistment. The model apparently offers the added advantage of being able to calculate optimal accessions over a shorter time period (the optimal dynamic policy). Some of the design concepts are implemented and running on an APL computer program, but work on this model has ceased and no final report is expected. Consequently, a va[illegible]sessment of the model's potential cannot be made.

While the Rand wo[illegible]nd ADSTAP have used nonlinear functional relationships to solve for steady-state optimal decision rules, the CNA approach was to make linear assumptions about productivity and supply in order to find a dynamic solution. Difficulties unlikely to be overcome preclude the use of models with realistic nonlinear functions and time-dependent (dynamic) variables, the chief difficulty being the overwhelming computational burden.

COPLAN, the UC Berkeley model of accessions in the Navy enlisted force, differs sharply from the CNA optimization model. Requirements in the chosen skill category must be specified for each year of the planning horizon. Retention behavior is made time-stationary and is assumed to be independent of cohort size and military compensation. The Berkeley model considers total accession costs as the cost objective to be minimized. However, total compensation is a more relevant cost measure from the larger-scale perspective.

Because requirements are again assumed to be invariate, it is possible that no solutions can be found. This model has limited applicability, being oriented primarily to accessions planning rather than managing the entire enlisted force.

Optimization models are unique among manpower models in being required to describe the effects of policy decisions on personnel flow. Often, however, either ignorance or the desire to maintain simplicity has caused this relationship to be neglected and feedback of policy effects that would be valuable to the model have been lost. One criticism we have is that these implicit relationships representing unmentioned assumptions should be presented more specifically and clearly.

Of the many DoD manpower models, by far the most have been nonoptimization models used in a descriptive and predictive mode. Many of these, however, have found increasing use as policy simulators with which planners can test the effects of policy alternatives. We have included such models in our survey because, although they do not perform internal optimization, they can be used iteratively to improve policy. We believe it a major flaw, however, that nonoptimization models accept historical accession and retention behavior as independent of policy

changes. This simply is a bad approximation of reality. Requirements and constraints are especially important. Grade management models, for instance, insure a junior force and inadvertently maximize accessions requirements because of the firm requirement for supervisors in grades E7-E9 and use of historical transition rates.

Each optimization model must be restricted to a workable subset of the thousands of types of decisions that planners can make. These primarily have been those modifying the force distribution by changes in retention rates, pay-grade management, career field, and training area policies.

Similarly, the number of real objectives is large and must be limited. Most models have been restricted to consideration of the long-run steady-state policy. The basic objectives of any military force are to maximize some measure of effectiveness within the budget available or to minimize the cost of achieving a specified level of effectiveness. These objectives have been translated for inclusion within each of the models in many ways, some correct and some incorrect. Furthermore, models may not be concerned with the complete manpower system but rather a subsystem. Policies determined by such models are suboptimal. The use of both faulty objectives and of suboptimal policies should be avoided.

Traditional and legal operating requirements have been placed on manpower systems, limiting the scope and type of policy variables. However, in the long run and particularly in large-scale planning, all manpower policies and regulations should be considered as open and subject to change. These include retirement policies and policies setting compensation through changes in bonuses, special pays, and fringe benefits. Changes in physical and mental standards and capital versus labor tradeoffs ought to be considered variable as well. It is ironic that models whose main applicability lies in long-run planning ignore some of the most important long-run policy variables.

Often we found that current models of operational systems indicate that the manpower system is simply overconstrained, and thus no feasible policy exists, let alone an optimal one. In the long run, it is reasonable to relax many of these constraints; in the short run, no feasible solution exists. Optimality must be redefined, much as has been done in goal programming. The danger there lies in the use of these arbitrary objectives, which have arisen by concentrating on requirements rather than productivity. In general, all optimization models have serious practical limitations. The simplicity necessitated by computational requirements limit the models' operational usefulness. The dynamic (short-term) optimization desired for daily use is difficult theoretically, but some attempts have been made to develop adequate approximate methods of this system.

In summary, then, some criticism can be leveled against the current state of the art as displayed by the six optimization models. Validation of the component parts, particularly in descriptive models, has not been made. Thus potential users have no idea whether even the indicated direction for change specified by the model will produce beneficial results. Validated models would allow statistical confidence in predictions and recommendations. Admittedly, few models in other fields besides military manpower are validated properly before use. This represents a serious shortcoming—evidence of an overanxious model builder—that is not peculiar to the manpower field.

Validation of nonoptimization models does not extend simply to their descrip-

tive or predictive ability. These models are finding increasing use as policy simulators. Part of the benefit from exercising models in this mode is the training and education it offers the user. The user learns what to expect from policy changes, how the manpower flow system reacts over the transient period, what the long-run implications are, what constraints have effect, which are violated, and so on. The implied usefulness of this role must itself be validated, to answer the question of whether a user gains beneficial manpower management experience by participating in a simulation. Management gaming in business schools has produced both positive and negative results. No one has yet made a comparative study of business and military gaming, but our judgment is that use of military manpower simulation models is beneficial on the whole.

Use of the wrong objective function is another common fault. This is to be distinguished from a suboptimization objective that may not fit optimally within a larger frame of reference. The use of cost-benefit ratios as an objective to be minimized is notorious for creating more problems than it cures. Hitch and McKean [25, pp. 166-167] discuss criterion errors of this form:

> To maximize the *ratio* of effectiveness to cost may seem a plausible criterion at first glance but it allows the absolute magnitude of achievement or cost to roam at will. Surely it would be a mistake to tempt the decision-maker to ignore the absolute amount. . . . In fact, the only way to know what such a ratio really means is to tighten the constraint until either a single budget or particular degree of effectiveness is specified. And at that juncture, the ratio reduces itself to the test of maximum effectiveness for a given budget, or a specified effectiveness at minimum cost, and might better have been put that way at the outset.

In defense of the cost/utile objective, the ADSTAP authors claim improvement in computational speed at the loss of a small error in the final policy. This claimed improvement has not been demonstrated by analytic proof or by simple examples; in fact the contrary seems indicated.

Many of the models are suboptimization models designed for operation in a lower echelon in the hierarchy of decisionmaking. In this environment many restrictions, regulations, and costs are invariate to the policymaker. Suboptimization models play a correct and valuable role here. Our criticism is that these models have not adequately set the stage of the decisionmaking environment where the model is applicable. Omission of that groundwork in the reports has misled the reader into thinking that these models have some global range of use.

Improper use of discounting of future costs was found in one case. This would produce a faulty objective function and faulty decisions. All model builders must take care to evaluate the present worth (and expected present worth in stochastic systems) from the point of view of the government planner. This is the most important cost measure of performance of any system, and only under certain conditions are average costing methods applicable. Further discussion of the misuse of discounting appears in an appendix.

Because good documentation of models is lacking, the transferability of models and expansion of the state of the art lags the development of models. We believe the field would benefit from improved documentations, critical review by qualified colleagues, and generally increased communication of ideas among DoD manpower modelers. These ideas are expanded in Chap. 4.

Chapter 4

RECOMMENDATIONS AND CONCLUSIONS

ISSUES THAT SHOULD BE ADDRESSED

This chapter summarizes the important factors to be included in military manpower modeling and concludes with general recommendations. Rather than describe what has been done and repeat why it is both good and bad, we take the prescriptive role and try to formulate concepts for model builders. This will help to produce superior models within the general philosophical view of Chap. 2, which describes force efficiency and the military decisionmaking environment. These factors and concepts need to be addressed explicitly during the development of manpower models.

The hierarchy of the management system within which decisions are made must be described when developing a decisionmaking manpower model. Omitted from most current models, it has been left to the reader's experience and intuition.

The model builder must first clearly describe this system and then discuss how and why all the crucial assumptions of the model are decided upon. These assumptions concern the constraints, requirements, and costs accepted as given by some higher level control. They are the result of this hierarchy. The planning policy that a model is designed to address is again a function of the management hierarchy.

For transferability and adaptability in other situations and different times, the model builder's assumptions must be clear and explicit. Too often they are implicit. When the model builder fails to depict the decisionmaking environment being modeled, the consequent difficulty of ferreting out the implicit assumptions severely limits the model's transferability and range of usefulness. Even explicit assumptions often seem absurd if they are glibly stated without reference to the decisionmaking framework.

Every model builder must keep in mind that the decision process being modeled fits as a subset into a larger decision process, and therefore is at best a suboptimization. Decentralized decisionmaking is characteristic of the military manpower planning process. The assumption set forming the basis for the model is a direct result of that decisionmaking environment. The relevance and accuracy of these assumptions, and therefore the model itself, can be judged only in relation to this decision hierarchy.

Productivity assumptions are important even when made implicitly, as was done in many of the models reviewed. Requirements constraints, total manning levels, constraints on the numbers of E-9s, etc., are examples of implicit productivity assumptions made in lower-level manpower decision systems. The tradeoff of personnel with different characteristics in terms of a contribution to various types of military effectiveness or output is the important measure of productivity.

We have seen a range of assumptions in the current class of models. Linear and nonlinear production functions were used successfully in several models. Requirements constraints were used in models farther down in the management structure. Even total manning level constraints represent assumptions on productivity of a

given force composition. In the large picture military capital equipment and manpower are the two principal determinants of military output. In this larger field for such decisions, the tradeoff allocations between money and ships or between planes and people would be addressed.

The fact that military effectiveness or productivity is difficult to measure and cannot be measured completely by a simple single-valued function of the force composition does not mean it should simply be ignored. In the real world, managers base their decisions on intuition and experience and judge tradeoffs between requirements and effectiveness. In doing so they implicitly measure military manpower effectiveness. Any manpower model purporting to improve decisions and policy must address the modeling of military productivity.

Supply of manpower to the military is the second major area needing thorough study before manpower models can properly be judged adequate. Prior to the AVF, demand determined the supply of first-termers. Now the entire law of motion describing the movement of personnel through the system is based on the supply of volunteer manpower. Theories based on behavioral and economic principles can be used to predict accession and retention behavior as functions of decisions affecting such important policy issues as military pay, tour length, rate of promotion, and retirement options.

Most of the current DoD models predict supply on the basis of elementary extrapolations of current real retention. Although this procedure is adequate in certain descriptive or predictive models, any model purporting to suggest changes in manpower or personnel management policies must consider how policy changes will affect the supply of manpower. A simplistic approach is warranted in certain suboptimization models of decentralized subsystems, but supply relationships, no matter how elementary, must be made explicit in most models.

The retirement system offers an important monetary incentive for retention in the services. Policies that affect retirement, the proportion retiring, or the basic system, in turn affect the supply of military manpower.

Enlistment and reenlistment bonuses and specialty pay are currently feasible ways to change the effective pay of different categories of people in service; they also affect retention behavior. The supply relationship is a function within the model that estimates the actual retention fraction for all of the bonus distribution options.

Costing methodology is a deceptively complex problem in manpower modeling. Discounting is a well-known technique for obtaining present value or cost measures for decisions that affect costs over periods to time into the future. Care must be taken to measure only the actual cash flow in each time period from the government, which is to be viewed as the decisionmaker, and to discount this flow of dollars properly. Its application in military manpower systems is dependent again on the way the model fits into the hierarchy of the larger decision environment. In some cases a budget constraint for each year is handed down, and total costs must be kept within the budget. No discounting is used in this type of suboptimization. Instead, a cost constraint is used. Under other conditions it may be relevant to examine average annual cost as a surrogate for discounted costs. These alternative costing methodologies are not interchangeable without careful analysis of each situation.

The objectives of manpower management vary with the situation. Short-term

versus long-term considerations must always be balanced. Risk is always present because of natural variability (randomness) and lack of adequate estimating data. The model builder attempts to develop a simple measure of performance as the objective to be optimized but is always faced with multi-attributed measures of performance in the real world. Consequently, it is easy to criticize any given set of assumptions. Both the objectives of military planning and measures of military effectiveness are multi-attributed concepts. Model builders must make reasonable simplifying assumptions and clearly motivate them for their models to have any value in military manpower planning.

Managers make decisions in the light of objectives, some of which are quantifiable and others not. The model builder, after structuring the decision hierarchy and gaining experience with the real environment, is well prepared for the challenging tasks of quantifying the objectives of military manpower management.

In summary, a successful model builder will

- Describe the decisionmaking hierarchy and, in particular, the subsystem where decentralized decisionmaking is to be improved.
- Make explicit assumptions as appropriate in the modeled environment on
  - Productivity measures of military effectiveness
  - Requirements and constraints
  - Supply of manpower
  - Costing methodology
  - Management objectives.

All military manpower models hoping to improve decisionmaking on more than a one-shot basis should include discussion of these issues and motivate their assumptions. The key to improvement in modeling will lie in increasing the communication and transferability of models. Only then will mistakes be recognized and not be repeated and the art and science of manpower planning grow.

RECOMMENDATIONS

We have found the current state of the art deficient in the several aspects discussed in Chap. 3. Recognition of these deficiencies, modeling failures, and chronic problems is the first step toward improving the quality of manpower modeling, and we hope this review will promote such recognition.

Below, we present policy recommendations for both model builders and their funding or sponsoring offices. Our recommendations are based on the discussions and observations that took place during the course of the project. Our primary sources of information were the written reports available on the models and our discussions with people in meetings and over the telephone during the last two years.

We offer our policy recommendations as potential prescriptive requirements to be laid down by funding agencies and as objectives for model designers.

Model builders should identify the level of modeling in terms of its place in an organizational hierarchy. Most models currently in use are suboptimization models; global optimization is nonexistent as yet within the DoD. Once the level is identified, the limits of applicability of the model should be defined. Within its level,

a model should be as general as possible, so as to allow the application to be defined by input parameter specifications from a higher level. Care should be taken to avoid inappropriate transfer of the model to the wrong operating environment.

Model building for its own sake should be minimized. Basic research may sometimes require the support of experimental modeling, but major endeavors should be justified by statements of need, estimates of development and operating costs, and analysis of benefits returned from implementations. It is important to begin small—to begin by working with prototypes on subsamples, developing hypothetical cases to test basic algorithms and to determine if the model's results are appropriate to the questions that need to be asked. Frequently, it is not known what output is really needed until initial experimentation with a working model is completed. Emphasis on working small in prototype modeling allows for modification and testing before a large investment is made in personnel resources, computer operation, time, and money.

Before a large endeavor is undertaken, a plan for operational use of the model after development and testing should be required. This plan may include a discussion of what part of the planning organization will use the model, what computers are available, who will interpret the results, and particularly important, who will take over as the driving force once the principal researcher has moved on.

Even with a well-developed plan for operational use, there will inevitably be continual revisions of data input for parameter estimates and report writers, and other refinements. A facility for such operational changes should be demonstrated. Programming teams with head programmers who write code using standardized structured programming techniques and modular construction will produce readable code that minimizes debugging and facilitates modifications. User orientation should be emphasized in design specifications. If input is elaborate, an input interface module that tests and checks input before execution should be written, especially if the model is to be used by planners and other non-computer-oriented personnel. Continued smooth operation of the model absolutely requires ample comments, variable dictionaries written in the code, and well-written, complete, precise documentation. Written documentation for all DoD-sponsored personnel should be required, and budgets should include salaries for program librarians with technical writing ability whose purpose will be to assist programming staff with all documentation-related activity.

Model documentation is a chronic problem that will be solved only by placing requirements on the type and quality of the technical reports to be produced. Good documentation encourages comments and open communication between modelers. A forum where models can be discussed and constructive criticism can be solicited will encourage a high level of technical competence in DoD modeling. Hidden, secret, or ambiguous segments used within a larger model do not further the development of DoD manpower technology and should be discouraged.

We hope we have succeeded in providing a systematic and comprehensive review of the important modeling contributions made to date, and in setting the stage for improved manpower modeling over the next few years. The all-volunteer force is at the center of the stage and efficient management of military manpower is the principal objective. In spite of our criticisms of the current state of the art, the prospects for enhancing the efficient use of DoD manpower through modeling are excellent.

Chapter 5

OPTIMIZATION MODELS

In discussing the current state of the art, Chap. 3 listed a number of large-scale optimization models that have recently appeared in the DoD in various stages of development: the effort under way at the Bureau of Naval Personnel to develop the ADSTAP [17] manpower planning system; the work in the Navy's Office of Civilian Manpower Management (OCMM) [18]; the Army's contract to develop an Enlisted Objective Force Model [19]; Rand's effort [20] under ARPA sponsorship; preliminary work on an Enlisted Personnel Projection and Simulation Model [21] conducted at the Center for Naval Analyses; and an optimization model for accessions to the Navy's enlisted force done for the Office of Naval Research at University of California, Berkeley [22]. These models are the only true optimization models we have found.

THE RAND MODEL

The Rand model features a broad level of aggregation and an abstract or theoretical (as opposed to directly practicable) manpower management policy. This research effort has produced a personnel model that attempts to find the best composition of the military enlisted force in the long run or steady state. It is designed to find a wage schedule and resulting force composition that maximizes steady-state productivity for a given military manpower budget. This objective is closely related to the economic concept of productive efficiency, which would imply a policy with the maximum output for a given cost, or alternatively, the minimum cost of producing a given rate of output. The authors believe such objectives are certainly valid for ARPA and OSD manpower planning, for which a long-range fundamental policy is formulated that can consider major structural and parametric changes to the operation of military manpower systems. At a service level of decentralized manpower planning, the objectives can seldom be so simply stated. The model treats military compensation and the rate of enlistment and reenlistment as variables. In fact enlistment and reenlistment rates are directly linked to military compensation in the model through supply functions.

This model seeks to determine the optimal composition of the military enlisted force aggregated by term of service. The optimal force is defined as that which provides the greatest military capability for a given budget cost. Since individual military personnel differ in both productivity and wage rates, force composition affects both military capability and manpower costs. Pay grades are not explicitly identified within the model; consequently, promotion policies cannot be evaluated.

As a general rule, the most productive force for any given budget will result when the incremental contribution to output for each term of service just balances the incremental cost of hiring an additional member in that term. This rather simplistic solution, however, is complicated by several factors. First, retaining personnel beyond the first term requires reenlistment; retaining a person for a fifth

term requires five separate enlistment and reenlistment decisions. Second, as numerous empirical studies have shown, enlistment and reenlistment depend upon military compensation, the total cost of which therefore is not a constant but depends on the number of enlistments and reenlistments required. Moreover, enlistment and reenlistment may be affected by compensation expected later on—reenlistment bonuses and retirement pay, for example. The problem of estimating enlistment and retention for each term of service occurs within a complex system involving various forms of military and civilian compensation for every term of military service.

A steady-state model of the flow of men through the terms of service is constructed. An optimization model chooses military compensation levels that yield the optimal size and composition of the force. An operations research technique called gradient search—a type of nonlinear programming—using a computer-based algorithm is used to solve the problem.

The choices made in developing this model were to treat nearly all aspects of the personnel system as variable, including retention rates and military compensation, and to develop a model that gives adequate representation to the considerable theoretical and empirical work done on manpower supply and productivity. As a result of these choices it was necessary to severely limit the number of variables contained in the model. Military manpower is differentiated only by term of enlistment rather than specific year of service, and aspects of the personnel system such as the grade structure are not included in the model. One result of developing the model was to show that considerable empirical work remains to be done on manpower supply and productivity.

The Rand model has inherent limitations. It has a high level of aggregation in describing the manpower distribution; thus, for practical policy issues, considerably more detail would be necessary that could greatly complicate the model. The model uses a simplified military production function, as opposed to the more common set of requirements constraints, and uses a steady-state analysis. Devising the correct production function and estimating its parameters would alone constitute a significant research project. Because of the assumptions necessary to maintain computational feasibility, the model loses its ability to specify decisions on a microscopic scale, for example, selecting a variable reenlistment bonus (VRB) for a particular specialty, determining the optimal number entering nuclear school, specifying the amount and specialty area for cross-training, etc. Additionally, it cannot specify decisions in the short run or over transient periods when rapid changes in force makeup are required. Its value lies in being able to determine the general makeup of an ideal objective force divorced from current institutional and Congressional operating constraints. Precisely the aspect that makes it unusable in today's environment makes it valuable as a long-run military planning tool.

MAD-P AND THE ADSTAP SYSTEM

The ADSTAP system of models, particularly the MAD-P optimization subsystem, has been under development at the Bureau of Naval Personnel to aid the Navy in enlisted personnel management. An interim report to the Office of the Secretary of Defense, "U.S. Navy Enlisted Force Management System," was published in June 1973 [17] with further update of progress expected.

The work attempts to model the complexities of practical personnel management. A number of models were developed and combined into the overall ADSTAP system. MAD-P, the optimization system, primarily of interest here, is composed of several of these models linked up to an optimization procedure. One model, ASTATIC, distinguishes the force by 31 different length-of-service (LOS) years and 7 different pay grades; it is currently used to help develop force structure objectives. Input to ASTATIC consists of loss behavior, attrition and reenlistment behavior, promotion opportunity and promotion zone information, and a size limitation for either the total enlisted Navy or for one particular specialty rating, or both. Recursive equations are derived from steady-state analysis that require in-flows to equal out-flows; these are solved numerically on the computer for the LOS and pay-grade distribution that results from the given set of inputs. Several descriptive models within the DoD (TOPCAP) are very similar to ASTATIC and will be discussed individually later in this report.

To perform the optimization, the ASTATIC model is coupled with a costing model and a utility model. The utility model is particularly interesting because it demonstrates the difficulty of measuring military productivity. A Delphi experiment was conducted under a contract to B-K Dynamics [23] to develop estimates of utility of an average enlisted man at a given grade and LOS within each of the specialties.

An Elasticity Dependency Model is used to modify parameters representing retention behavior for the ASTATIC force determination model as functions of the decision variables. The basic policy variables are increases or decreases in continuation rates from some historical norm. The changes may be thought of as being stimulated by enactment of a Zone A or Zone B selective reenlistment bonus (SRB), or by a reduction in force (RIF) policy that might require, for example, a separation pay penalty. Bonuses and severance pays are merely proxies for the cost of changing historical continuance rates. Other measures would serve equally well; for example, the RIF penalty might represent the loss in human capital due to the layoff of trained personnel. With the elasticity dependency model, the costing model, and the utility model, optimization can proceed. The current objective function to be minimized is the average cost per unit of utility ($/utile), taking the total annual cost of a given manpower plan and dividing by the total utility of the resulting static force composition from ASTATIC. The basic control decision variables are continuation rates for personnel in each of the various grade and LOS cells of the state description matrix. Currently, this consists of 12 variables: 6 continuation and 6 advancement rate variables. A nonlinear numerical search technique is being used to converge to a point where the 12 partial derivations are equal to zero, representing a local optimum of the objective function. Current implementation takes 35 CPU minutes per specialty to converge.

The system encompasses several other important models. The FAST model [5] (also discussed later in this report) can age the current force into the future in three dimensions (pay grade, LOS, and occupational specialty) using anticipated policy for promotion, accessions, and enlistment. The outputs are used to project levels for procurement, budget, and training activities. The FAST system projections can be evaluated with respect to cost and utility measures of output for simulation of policy alternatives. However, ASTATIC rather than FAST is used in the MAD-P optimization of ADSTAP.

The MAD-P optimization handles only one Navy specialty at a time, thereby avoiding the complex issues of intraspecialty tradeoff in productivity or utility measures. Each specialty is viewed as a closed manpower system; entrance and progression up through the ranks are the only way to gain experience and a higher pay grade. Manpower requirements in the specialty rigidly fix the total number of personnel. This assumption essentially says that intraspecialty tradeoffs are not productive or that the elasticity of substitution is zero.

Although the ADSTAP system of models demonstrates some excellent insights into the complexities of personnel management problems, its limitations are important to recognize. The authors consider as variable one of the many manpower policies available to the Navy—chiefly the SRB program, severance, or any other policies for stimulating or reducing retention. This approach must accept many of the constraints and traditions present in current manpower practices. For example, in setting requirements, "the number of men required to perform a given function or man a given unit are considered to be the absolute purview of the work engineering standards process . . . the rating required for a given amount of services is determined through a process of combining the skills and knowledge required to perform the services (work engineering) and the qualification for advancement in rating . . . this determination is unequivocal" [17:II, p. 2]. As the remainder of this survey indicates, ADSTAP is not the only system of models to contain such limitations and, in fact, it permits more policy options than almost any other model.

The Navy has set numerous goals for their manpower management system; for instance, "The Navy's goal is to attain a personnel management system based on efficient management with individual equity" [17:II, p. 1]. "The Navy opted for the development of a set of goals for the enlisted force which were developed and maintained by the line shops responsible for enlisted force management, for the development of goals which incorporated the notion of an ideal force" [17:I, p. 2]. "The essential element of goal setting for enlisted force management entails the specification of some idealized distribution of the force along specified dimensions" [17:I, p. 2]. "The Navy's policies will be directed to the extent possible to manipulating continuation behavior primarily through the application or withholding of incentives both pecuniary and nonpecuniary and by adjustment of the pay grade dimension of the requirements process to achieve this idealized force" [17:II, p. 4].

These are all desirable but often conflicting goals. The ADSTAP system has attempted to come to grips with all of them; it fails, however, because the constraints on operational personnel management policy limit many of the essential options in optimization models that would make them useful for large-scale and long-range force planning decisions.

The results of the per capita cost model and the utility model

> will be combined with the elasticity dependency model and the optimization model will be developed . . . the primary objective function is to minimize cost per utile per man-year. . . . The only fixed parameter will be the number of jobs to be done by rating. In other words the model will not attempt to justify the validity of the number of radio men required but it will be free to vary the pay grade structure in search of an optimal distribution. The optimization model will be free to vary advancement parameters, input mix, continuance rates as necessary to determine an optimal solution. When varying continuance rates, an approximate penalty cost will be attributed based on pay elasticities [17:II, p. 16].

Consequently, ADSTAP takes as input the number of men required in each rating, including supervisors, journeymen, and even personnel in the training pipeline.

The objective function in the ADSTAP model is to minimize cost per utile per man-year. Problems should be anticipated, because without the constraints imposed by ADSTAP on requirements, the force will contain only one extremely productive man, since marginal productivity per dollar is a decreasing function of the size of the force. Research is under way on this problem and may lead to the use of other objectives. The ADSTAP documentation states,

> Conceptually a force structure of minimum cost and maximum utility would be termed optimal. Equivalently, an optimal force structure minimizes the cost per utile. However, it can be demonstrated that minimizing the cost per utile ratio does not guarantee that the overall Navy is optimal referenced to the same ratio (cost per utility). To avoid such problems, an alternative objective function based on marginal cost per utile is being evaluated [17:III, p. 25].

This second proposition, made by Navy researchers to minimize the marginal ratio, is to minimize the slope of a generally convex increasing function. The earlier criterion minimized the angle of the secant drawn through zero on a plot of total cost versus total utility.

The field of operations research and economics, through decision theory and economic efficiency, sheds some light on the question of the proper objective function. Theoretically, the proper procedure would be either to maximize the productivity rate subject to a constraint on the annual budget or to solve the dual problem of minimizing the annual cost subject to a constraint requiring productivity to be at least a specified amount. This problem can be coupled with the institutional constraints imposed by Navy policies. The problems of using ratios of cost to benefit as decision measures, such as cost per utile, are well known.

In fact, Hitch and McKean [25, pp. 166-167] discuss criterion errors of this form: "To maximize the ratio of effectiveness to cost may seem a plausible criterion at first glance but it allows the absolute magnitude of achievement or cost to roam at will. Surely it would be a mistake to tempt the decisionmaker to ignore the absolute amount.... In fact the only way to know what such a ratio really means is to tighten the constraint until either a budget or particular degree of effectiveness is specified. And at this juncture the ratio reduces itself to the test of maximum effectiveness for a given budget, or a specified effectiveness at minimum cost, and might better have been put this way at the outset."

Its use in the MAD-P optimization results in a solution that is close to but not exactly optimal. The model developers have reported that the objective of cost/utile speeds convergence of the optimization algorithm and this justifies its use.

We have discussed two approaches to the optimum force structure problem: The ADSTAP approach minimizes the ratio of cost to utility for a given manning level; the economic efficiency approach minimizes cost for a given minimum utility and a given manning level. In the latter approach, specifying different utility levels enables us to trace out the efficient frontier: the locus for which cost is at a minimum for any given utility. Figure 5.1 shows two such loci, drawn under the assumption that the marginal cost of additional utiles is increasing throughout the entire range. The loci represent the case (aa') where no manning constraints are imposed and the case (bb') where the number of men must equal M_0. In the unconstrained case, the

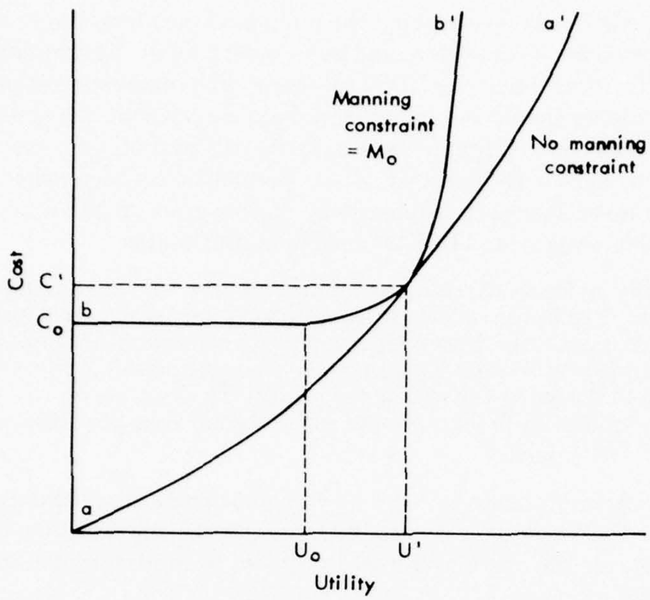

Fig. 5.1—Loci of efficient points under manning constraints and no manning constraints

number of men is an increasing function of the utility level and the minimum cost level, and where the number of men is M_0, the two loci coincide. Under rather weak conditions there will be only one such point (U', C'). Note that the constrained case can never have lower cost than the unconstrained case. In the constrained case, as the utility level declines, there is some point at which costs begin to increase again. But since utility is a minimum constraint, the efficient solution will have cost C_0 and utility U_0 over the range of minimum utilities less than U_0.

Figure 5.2 shows how the ADSTAP approach and the economic efficiency approach choose a level of utility and cost for the case where total manning must equal M_0. Under the ADSTAP approach (Fig. 5.2a) of minimum cost per utile, a ray from the origin is rotated clockwise until a point of tangency is reached with the efficiency frontier. This is the minimum cost per utile which satisfies the manning constraint. In the unconstrained case portrayed, minimum cost per utile would be achieved near the origin. Hence, the manpower constraint is necessary to obtain a meaningful solution under the ADSTAP formulation of the problem. The economic efficiency solution (Fig. 5.2b) requires a bit more explanation. A point on the efficient frontier has the property that the ratios of marginal cost to marginal utility are equal for every class of labor input actually employed (true for points to the right of the minimum utility). This ratio is represented by λ, which can be interpreted as a Lagrangian multiplier. This interpretation comes from the formulation of the problem as

$$\text{minimize } C(M_0, \ldots, M_n) + \lambda[U_0 - U(M_0, \ldots, M_n)] \; M_0, \ldots, M_n$$

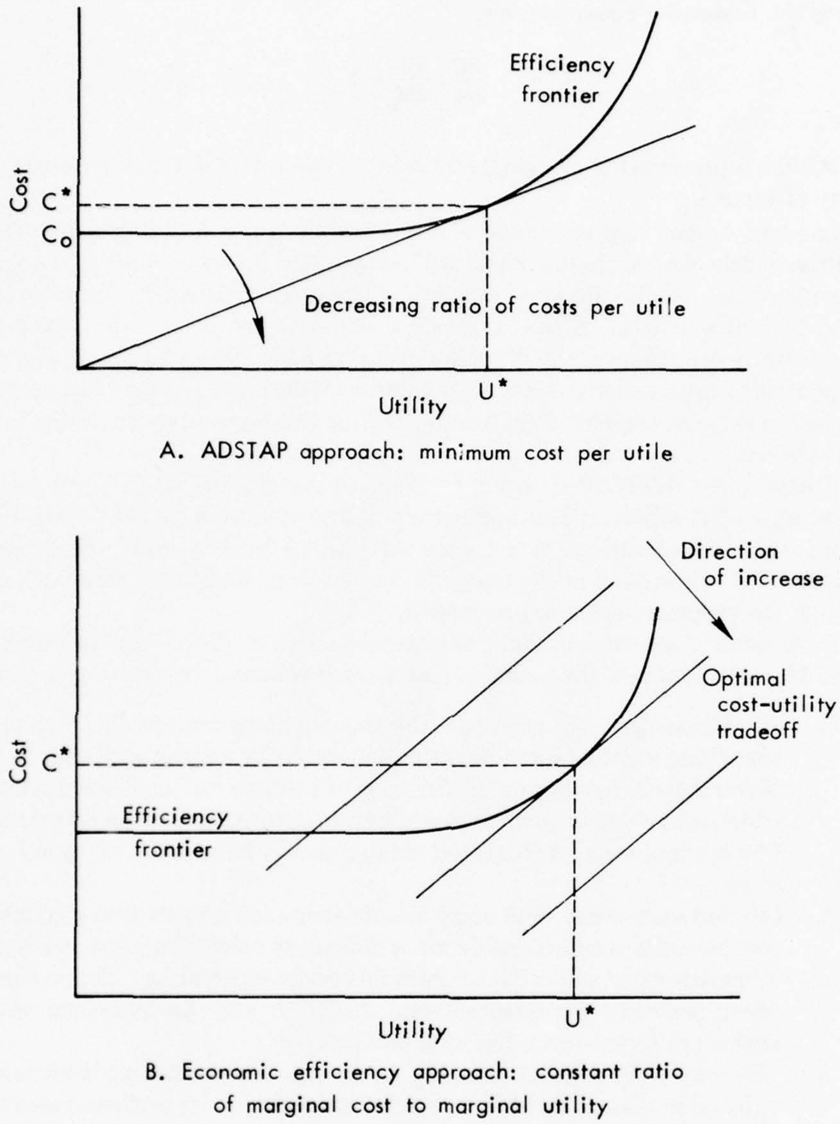

Fig. 5.2—Two approaches to the choice of level of utility and cost for optimum force structure

where the first-order conditions are

$$\frac{\partial C}{\partial M_i} / \frac{\partial U}{\partial M_i} = \lambda$$

and $\partial C/\partial M_i$ represents the marginal cost of input i and $U/\partial M_i$ represents marginal utility of input i.

Lambda, λ, may also be viewed as the price the Navy is willing to pay for an additional utile. And since the model will be operated for every rating, one would expect the price λ to be the same in every application. Figure 5.2b shows how the optimal point is chosen. A line with slope equal to the price λ is moved in a southeasterly direction (in the direction of increasing utility and decreasing cost) to a point of tangency with the efficiency frontier. If the same λ is specified for every rating, the slope of the efficiency frontier will be the same in every rating at the point chosen.

Applying the ADSTAP criterion to every rating produces a different ratio of cost to utility in each field. This is less than desirable since it would be possible to reduce costs over all ratings at the same total utility level by making the ratio of marginal cost to marginal utility equal for every rating. This is the result achieved through the economic efficiency approach.

In summary, we can highlight the consequences of differences between the ADSTAP formulation of the problem and more traditional economic approaches.

1. By minimizing cost per utile, the modelers circumvent the problem of specifying a dollar cost per utile that the Navy would be willing to pay. Nevertheless, this is done at the price of a somewhat haphazard solution, which is likely to be inefficient when specialty ratings are done separately. The optimal force of combined ratings should have equal marginal cost/utile.
2. Limited experience with some simple examples reveals that minimizing cost per utile is considerably more difficult to solve computationally than minimizing cost subject to a minimum constraint on utility. Hence, convergence problems experienced with ADSTAP may be overcome with a slightly different formulation of the problem.
3. The treatment of total manning as an equality constraint is somewhat unusual in view of the fact that different utility levels are associated with different types of individuals. Normally one would expect that fewer more productive individuals could substitute for more less productive ones. But if this is not possible, the meaning of different utilities is not clear and it is not obvious by what process the Navy benefits from higher utility. These are rather subtle issues, dealing with the relation of naval capability to manpower inputs of various kinds, and aside from adopting a different approach in the Rand model we have no special insights in this area at this time. In the more traditional economic approach, the utility function is replaced by a production function that includes all variable inputs. The quantities of each category of inputs can be chosen to produce a desired level of output in the least costly manner. Constraints on the total quantity of one category of inputs are not usually included. Hence in this context the total manning would be variable, just as in the unconstrained case in Fig. 5.1.

Standard criticism can be made of the linear character of the production function used in MAD-P. But another area of debate has arisen in the measurement of productivity or utility: the method of estimating an individual's relative productivity. The Delphi questionnaire method used [23] resulted in extremely large relative differences in productivity. For example, one 20-year man was worth five 3-year men. The argument made in favor of this is that utile tradeoffs across specialties are not nor were ever intended to be made. The MAD-P system, then, is strictly viewed as an optimization of pay grade/LOS within a specialty rating. Instant promotion for almost everyone on the force would automatically raise the productivity measure of a force with the same LOS distribution. Even with internal constraints, the tendency of the model to promote as rapidly as possible to raise productivity will always remain.

This critical analysis of the ADSTAP system is not meant to detract from the value of the overall attempt. The effort may prove extremely valuable and represents a significant improvement in DoD personnel modeling. It is a system that has recognized and challenged the major problems of combining practical implementation and disaggregation (microscopic decisionmaking) in the framework of an optimization model. The difficulties mentioned here can be remedied fairly simply; moreover, the sponsors and developers of the model are in the process of reviewing their work to date. It is to be hoped that this review will take account of the points raised here.

GOAL PROGRAMMING IN THE NAVY'S OFFICE OF CIVILIAN MANPOWER MANAGEMENT

Goal programming is particularly useful when the aim is to meet conflicting goals as closely as possible. This technique transforms a model with nonlinear objectives and linear constraints into an ordinary linear program for solution purposes. Many of the personnel models using goal programming minimize the sum of absolute deviations from the goals. Other metrics could be used as long as the transformation is amenable to a suitable solution procedure.

The minimization of the sum of absolute deviations from constraints is a typical goal programming formulation. Conventional L.P. codes can be used when the absolute value of the deviation is the penalty function and the constraints themselves are linear. Quadratic or nonlinear programming codes must be used with nonlinear constraints and a conventional weighted sum of squared deviations. The problem when a simple sum of squared deviation is used for a set of linear equalities is solved by the standard least squares regression codes. Once this is secured all the power of existing computer codes is at the disposal of the model builder. Since 1967 the Navy's Office of Civilian Manpower Management [18] has been developing a wide variety of applications to use goal programming for managing the Navy's civilian labor force. Applications to multilevel military-civilian planning [25], to officer distribution [26], and to dynamic multi-attribute organization design [27] have also been suggested via algorithmic and prototype developments.

The series of goal programming models is impressive because it is directed toward the user of the system, who can be totally ignorant of the theory, mathematics, or computation of the model. (See [28]). In an interactive computer mode of

operation it can be used by any analyst at any level of management in planning, policymaking, and evaluating alternatives while sitting at a desk-top terminal. Current applications are aimed at Navywide civilian career planning and at local installation planning. The batch processing mode is used for larger problems, such as those occurring in comprehensive studies conducted in response to questions asked by the Office of the Secretary of Defense and by the Office of Management and Budget.

We cannot begin to cover all of this work in the present survey. Instead we shall focus on the series called "OCMM Models," with which this work was begun. These embed a Markov process description of manpower flows within a goal-programming framework to yield a new kind of "Markov decision process" models. Here the term "Markov decision process" refers to recommended decisions designed to produce certain expected states. For instance, recruitments and RIFs might be recommended to produce expected states in specified manpower-job categories in each of a sequence of time periods. These recommendations are effected through "goal programming" in order to come as close as possible to manpower ceilings stipulated in each relevant category while allowing for transfers between categories that accord with specified Markov processes. Deviations above as well as below "ceilings" are tolerated in these goal constraints. Violation of other constraints, such as totals budgeted for salaries and work-related expenses in each relevant time period, is not allowed.

The dynamic model describes the movement of persons through a system where manpower is characterized by grade (GS-1 to GS-18) and major occupational group. Recursive equations relate the number on board in each descriptive cell for next year with the number this year plus new hires minus fires. These relationships hold in strict equality. Natural promotion rules, transfers, and resignations are included in the dynamic description of the force in the form of a year-to-year Markov transition matrix.

Job requirements for manpower in each job category or cell are specified for each year, and some penalty weight is assigned for excesses or deficiencies in the number of personnel. The magnitude of the budget, the limits on personnel by grade level, and particular Congressional, DoD, or Navy rules on force makeup are included as inequality constraints.

The penalty function is based on weights assigned for failure to meet manpower requirements. If hires and fires are costly, additional weights can be included to penalize this activity.

In the aggregate planning models that are currently operational, the manpower requirements are set as goals to be obtained, as shown in Fig. 5.3. A penalty is paid whenever the manpower requirement for a given category is not met. Relative penalties are also paid for adding to or reducing the work force. The fulfillment of the manpower requirements is then subjected to a number of constraints. First, the number on board in each job category at the start is set equal to a constant. This ensures that the base-period populations are then submitted to a matrix of movement, or transition rates, which distinguishes probabilistically between those staying in a particular job category, those moving to another job category, and those leaving the organization. This process continues in a network fashion for the number of periods to be included in the model. In addition, constraints are set for manpower ceilings and manpower salary budgets for each of the periods.

		Positive goal discrepancy	Negative goal discrepancy	On-board manpower	New hire manpower	Excess manpower	Sign	RHS
Objective function:	Relative priorities	β	β		γ	δ		Objective function
Constraints:	Manpower goals	-1 -1	1 1	1 1			= =	Manpower requirements
Constraints:	Manpower attrition			1 -M 1 -M 1	-1 -1	1 1	= = =	*Initial* POP 0 0
Constraints:	Total manpower constraints			1111 1111			$\leq$ $\leq$	Civilian manpower available
Constraints:	Salary budget *constraints*			(\$/m)1 (\$/m)2			$\leq$ $\leq$	Civilian salary budget

Fig. 5.3—Matrix details for civilian manpower goal programming models
SOURCE: A. Charnes, W. W. Cooper, and R. J. Niehaus, *Studies in Manpower Planning*, U.S. Navy Office of Civilian Manpower Management, Washington, D.C., 1972, Fig. 3, p. 1-13.

Explorations via sensitivity analyses, etc., make it possible to examine the consequences that might attend alterations in one or more of these goal or budgetary constraints. Furthermore, interactive computer capabilities are available in conversational modes that make it very easy to conduct sensitivity analysis on the (Markov) transition rates, the weights that might be assigned to deviations from goals, or the alterations in expected salary scales and total budget amounts. Finally, the whole is tied into an extensive data base called CAMAS (Computer Assisted Manpower System) from which studies may be essayed in "batch" as well as "on-line" (continuous) modes.

Large problems of this type (i.e., 3000 equations or more) can require large amounts of computer time, but probably much less than comparable models using simulation languages such as GPSS, as in the case of the Air Force and parts of the ADSTAP system. Research is under way [29, 30] to find ways of using the special structure of goal programs to obtain an explicit solution or an advanced start to the solution of the underlying linear program. These computational extensions may produce as much as a factor-of-ten reduction in computer time usage. Small problems (800 to 1000 equations) can be solved in one to two minutes and are quite suitable to interactive conversational applications.

The OCMM models and similar variations assume that the operating requirements are inflexible. The penalty weights given for absolute deviation from these manpower requirements are necessarily arbitrary. There is no theoretical basis at present for estimating these values. Similarly, the inclusion of penalties for hiring and firing cannot yet be justified or estimated. While it is possible to estimate an immediate dollar cost for hiring and firing, longer-term effects are difficult to measure. Moreover, the relative weights between this penalty and the penalty for failure to meet manpower requirement objectives, for instance, are only heuristical-

ly and intuitively based. Experience has shown that these penalty weights should be set to establish general precedence relationships (e.g., release personnel only as a last resort). Detailed control of requirements can be included through establishing upper or lower bounds on the goals themselves.

The approach of goal programming is well suited for governmental or military program planning where manpower requirements should be evaluated within given manpower and budgetary constraints. This differs from industrial models where profit maximization or cost minimization is paramount. In any case, application of these or any other models requires careful consideration of the underlying assumptions.

It can be questioned, then, whether the optimization approach of goal programming is at present suitable for large-scale high-level manpower management decisions. Certainly, application requires careful study of the constraints and penalty weights. It is valuable in its present use, however, because job requirements, budget, and staff limits are to some extent exogenous to the manager of a facility who is forced to make the hire-fire decisions.

COHORT PLANNING MODEL: COPLAN

Research sponsored by the Office of Naval Research is being conducted at the Operations Research Center of University of California, Berkeley, on the optimal rate of initial accessions [22]. The approach used identifies individuals by LOS only and examines skill specialty categories one at a time, although extensions of the work are planned to consider transfers and other interactions between skill categories.

The flow of manpower through the system is modeled in COPLAN using a concept quite different from the rest of the DoD personnel models. Because COPLAN is a longitudinal rather than cross-sectional analysis, it retains information on the LOS cohort. The cross-sectional view of a manpower system depicts the state by the number of personnel in each LOS cell. A discrete Markov transition process is the basis for flow behavior of these models. Longitudinal models describe the current system status by a state descriptor, a vector of accessions over past years, long enough back to include the size of the entire cohort of the oldest person in the force. Retention behavior during the advancement of each cohort is made dependent on each cohort as well as length of service.

Evidence exists that the cross-sectional data of transitions by LOS cell used to estimate the Markov transition probabilities of traditional models is not sufficiently stable over time for reliable prediction. In theory, longitudinal analysis adds an important explanatory variable in predicting the future. Using this approach, the authors report significant improvement in fitting the data and in estimating future retention.

The rate of accessions into the first year of service is the only variable under the control of manpower planners. The number of personnel available to meet requirements in any year is equal to the sum of survivors of each of the earlier cohorts plus the current number of accessions. All individuals, no matter what their

lengths of service, are assumed to be equally able to perform the job requirement in the skill category.

Manpower requirements over the next T periods are given exogenously along with survivor fractions by length of service. Input data on past accessions are used to calculate the legacy (those already in the job positions resulting from earlier accessions) present or expected at each period of time. This forms the basis of the requirements equations. Two basic simplifying assumptions are made. The survivor fractions are time-stationary, and the requirements equalities can have slack or excess personnel.

The objective function is the total present worth of all future accession costs. If the planning horizon is extended to infinity, the problem is what is called infinite programming, a mathematical program with an infinite number of decision variables. In this case, under certain restricted conditions, the computational effort can be truncated at a finite time and the infinite solution approximated by the solution to the finite problem. The model as presently formulated requires the solution to a linear system of inequations and a linear objective function, which are solved by standard linear programming codes.

Some practical methods are discussed to obtain estimates of the survivor fractions, which are important inputs affecting the optimal rate of accessions. A numerical example is presented where requirements become stationary after the sixth year of service. This removes the necessity for and benefit of the longitudinal cohort-following model. In this case, when the system reaches stationarity of input parameters, the exact solution to the infinite programming is obtainable.

As the authors note, the model has limitations in considering accessions as the only decision variable. "It is misleading to state the problem as if the accessions are the only variables which the decisionmaker can influence. The legacies, requirements, and to some extent the survivor fraction can all be changed or explicitly influenced by manpower policies" [22, pp. 4-5]. The enlargement of this approach to include several skill ratings or to include the grade structure leads to severe computational difficulties. However, in groups of skill levels where there is not significant lateral entry, the model has value in determining the accession plan, provided requirements do not change over time.

Lateral entry representing cross-training or dual training outside the primary skill rating may be in fact an important factor that manpower planners can influence or may be a common phenomenon of personnel movement. The model itself can be expanded without difficulty to include several skill levels or at least the major ones where such movement is common, but the management decision options of cross-training cannot be optimized because of computational difficulties. One of these difficulties is that the model becomes a nonlinear program when these survivor fractions are allowed to be control variables.

Another conceptual problem exists, one similar to that in goal programming of the Navy's OCMM Model, in that requirements are specified. While all model builders have recognized the problems of estimating these requirements and the illogic of making them absolutely invariate, few modelers have attempted to overcome them simply because it is extremely difficult to do so. The concept of military production has not succeeded in replacing these requirements.

THE ENLISTED PERSONNEL PROJECTION AND SIMULATION MODEL: CNA

The Center for Naval Analyses has two personnel modeling efforts under way. The CNA Officer Projection Model (OPM) [9] is basically a descriptive model of force aging and is discussed later in this report. The Enlisted Personnel Projection and Simulation Model (EPPSM) [21] has been developed to aid in projecting manpower structures under various conditions. For instance, variation is permitted in (1) continuation behavior; (2) training patterns; (3) concepts of measuring total force productivity; (4) cost factors; (5) compensation policies; and (6) budgetary or force level constraints. This model was developed with the enlisted Navy in mind but, as with many models of military manpower, only modest modification is necessary for application to any military service. The model has reached the development and test stage and is programmed for use in APL. The final reports are not available and are not expected to be, as development has ceased.

In its design, the EPPSM can be used in a simulation mode using base case parameters and a specification of an input stream of accessions to estimate and predict the time-dependent manpower flow. The state space description variable breaks the military force down by length of service only; in fact, the author feels that "pay grade is a poor and even perverse management tool, and it will remain so until the functions of monetary compensation are separated from the functions of rank, the latter considered primarily as a measure of quality and experience" [21, p. 25].

Linear equations and inequations (where excess personnel are permitted) which are recursive in nature describe the flow of manpower by length of service through real time. This is the same longitudinal approach used as the basis of manpower flow in the COPLAN model. The decision variable in question is cohort size specified as the yearly accession rate. Reenlistment behavior is assumed to be a linear function of cohort size, where the larger the size of the cohort, the smaller the retention rate. This specifies a linear set of recursive equations of the manpower flow process.

Effectiveness, measuring a concept called military force productivity, is modeled as a simple linear function of the length of service of each individual. The user is free to assign any set of values to this vector of productivity weights. Alternative parameters for this linear productivity function are suggested; for example, two classes are defined, effectives and noneffectives, and given a weight of one or zero. Students and other noneffectives are included with zero weight; others are included with weights to indicate measures of effectiveness against some standard. As a simplification, effectiveness is estimated by the "end strength," the total number of personnel in the system, in which each person is equally productive.

Compensation by length of service includes retirement costs and certain training costs. Retirement costs are incorporated by finding the equivalent annual cost of buying an annuity equivalent to the current lifetime pay in the retirement system. These amounts are made constant fractions of pay and allowances in each year, adjusted for the probability of reaching retirement.

The objective can be stated in primal or dual form of linear programming to minimize total discounted costs subject to a constraint on effectiveness or to maximize effectiveness subject to a budgetary constraint. The author notes that the system of constraints or targets may be over-constrained and so have no feasible solution. Goal programming is suggested as a way out of this dilemma. Since all

equations are linear equalities, weighted least squares regression can also be used to find the best accession pattern that gets as close as possible to all constraints.

This model is still in the development stage, and no practical results are available. The authors have addressed most of the important manpower planning issues in the design concepts and partially implemented these in a model written in the APL computer language. Key aspects of this general approach are (1) the idea of productivity and force effectiveness; (2) the use of discounting and inclusion of retirement (modified by probability of receiving this pay); (3) the treatment of compensation in earlier years; and (4) a modest attempt at including variability in the law of motion through a modification of the continuance rates of the manpower system.

The model attempts to find the optimal dynamic or immediate-term decision, unlike steady-state approaches such as ADSTAP or the Rand model. It will perform the optimization relying on linear programming or linear regression. These approaches require that a model be limited to certain linear relationships between pay, reenlistment, and productivity measures. It is not known how limiting the linearity requirement might be, nor are any numerical results available at this time for any substantive evaluation.

SELECTIVE REENLISTMENT BONUS, ENLISTED OBJECTIVE FORCE MODEL

The Military Personnel Center, Department of the Army, has contracted with Systems Automation Corporation to develop a model for managing incentive funds such as the variable reenlistment bonus (VRB). This model has been called *SRB/Selective Reenlistment Bonus* [19] and it is hoped that it will prove useful in prescribing policies to achieve an objective force characterized by military occupational specialty (MOS) as well as the years or length of service (YOS). Input to this model will be the projected force as determined from a Personnel Inventory Analysis System II model (PIA II) [32], which projects monthly the LOS distribution within the Army by MOS, grade, and years of service, and the objective force as determined by simulation runs of other steady-state static models available within DoD (such as DEMOS—discussed later). The projected force is compared with the objective force and the annual reenlistment requirement and accessions are established.

The manpower system is over-constrained; that is to say, there is no feasible accession or reenlistment pattern that can be found to meet all the requirements imposed on the system. This situation often arises because of the diversity of decisionmaking and a large number of objectives and constraints that challenge military manpower planners. A goal program is set up to try to minimize the violation of certain sets of requirements. Linear programming can be used here since the penalty function chosen is the weighted sum of absolute deviations. The model is still undergoing development. The approach is similar to the work of the Navy's Office of Civilian Manpower Management. The size of the line or program presents computational problems when the Army is subdivided into MOS, grade, and LOS.

Neither documentation nor numerical results are available for this model,

although documentation was promised in early 1975. Therefore, our evaluation and presentation are necessarily sketchy. The model is subject to the same criticism directed earlier at other goal programming models, since it treats manpower requirements as exogenous. Generally speaking, this approach will aid in suboptimization, where requirements are specified. The objective function in such problems is artificial, and it is purely a matter for speculation as to how such models ought to be used for long-range or broad manpower planning. Whether the computational expense justifies its use even as a suboptimization decisionmaking tool is still open to question.

CHAPTER 6

NONOPTIMIZATION MODELS

The 20 nonoptimization models reviewed are discussed individually in this chapter. The terminology and framework developed in Chap. 3 are used to describe their features. (Refer to Table 3.2 for guidance.)

CLASSIC TOPLINE MODELS

Because these models were among the first to be operational in the Air Force planning process and, more important, because they exemplify problems that have to be solved in personnel modeling, STATIC and DYNAMIC TOPLINE are discussed here to be used as a comparative reference point throughout the report. It will be evident, especially in the discussion of STATIC DOPMS and DYNAMIC DOPMS, how some of the limitations of these early TOPLINE models have been dealt with in the evolution of newer models. It should be stressed, however, that these TOPLINE models are now obsolete and that they are included in this state-of-the-art survey for background information and illustrative purposes.

STATIC TOPLINE MODEL

Basically, the STATIC TOPLINE model [33] was designed as a grade management model to assist in reaching an "optimal distribution of Air Force Officers" by years of service. It was intended to assist in analyzing long-term personnel objectives and in testing the long-term effects of personnel policies. Design of the model facilitates this analysis by its input and what parameters it allows to be manipulated as decision or policy variables.

In terms of the structural attributes previously described in this report to characterize models, TOPLINE is most illustrative in its level of aggregation, its steady-state conditions, and its method of deriving the main computational array.

Because STATIC TOPLINE is an aggregate model, the total officer force is distributed among cells or states with respect to classification factors. These factors include component (Air Force Academy, contract, regular, reserve, other); grade (four categories: captain or less, major, lieutenant colonel, and colonel or above); aeronautical rating (pilot, navigator, nonrated); and years of service (1, ..., 35). These attributes correspond to dimensions that identify and index personnel as they move through the model. The model is limited to analyzing only these characteristics of the makeup or composition of the force. In a sense, then, STATIC TOPLINE models average behavior within the personnel system.

Like most models designed to study long-term objectives, TOPLINE is steady-state. Equilibrium conditions apply, which require that additions to a state are equal to losses from a state. Generically, TOPLINE can be thought of as a Markovian model insofar as progression to the next state is only a function of the present

state. These changes of state result from policy variables (model inputs) such as accessions, training rates, length of commitments, force-out years, retention rates, and promotion opportunities.

The mathematics is based on elementary probability theory and some basic notions from operations research. Two computational algorithms are of general interest. The first finds the distribution of men over years of service; the second finds the distribution of men over grades for any given year of service.

The "smear technique" solves the first problem: Given the total number of officers required and a set of retention rates, where $r_0 = 1, 0 \leq r_t \leq 1$,

$$N_t = r_t N_t m_0$$

where $t = 1, \ldots, 35$, and
N_t = number of men in t year of service,

find the distribution of numbers of officers over years of service.

To solve this problem it is necessary to know the number of men in the first year, N_0. The yearly number of accessions is referred to as the arrival rate. Next, the expected career length is computed so that the number of accessions, N_0, to the system can be determined by use of a flow equation, $M = N_0C$, where C is mean time in the system and M is the total number of men. From this equation N_j's can be computed as $N_j = c_j M/c = c_j N_0$, where the survival rate c_j is defined as the fraction of accessions who did not leave before the $(j - 1)r_t$ year, and is computed by

$$c_j = \prod_{t=1}^{j} r_t$$

where r_t are retention rates.

To solve the second problem of finding the distribution of men over grades, a recursive technique generates a distribution matrix $X_{t,g}$, which gives the proportion of the total number of people for year of service t that are in grade g. By applying retention rates to $X_{t,g} N_t$, it is possible to determine the number of people who will move to the next cell, so this matrix is the main computational array of the program. The following conditions must be satisfied in generating this array:

For all $X_{t,g}$; $t = 1, \ldots, 35$ and $g = 3,4,5,6$

$$0 \leq X_{t,g} \leq 1$$

where $$\sum_{g=3}^{6} X_{t,g} = 1 .$$

The $X_{t,g}$'s are derived from probabilities called promotion opportunities, $0_{t,g}$, which are numbers between zero and one that are supplied as input to a model to provide a basic parameter for the law of motion. For year of service t and grade g, $0_{t,g}$ is the probability that an officer will be promoted to grade g or higher in year t. The relationship $X_{t,3} = 1 - 0_{t,4}$ means that every officer who is not in grade four

or more is in grade three. Because grade three is the lowest in this model, this statement is true. The probability that an officer is in grade four or more ($0_{t,4}$) times the probability that everyone is in grade five or less ($1 - 0_{t,5}$) gives the probability of being in grade four.

The calculations proceed recursively to yield the distribution of men over years of service and grade:

$$X_{t,4} = 0_{t,4}(1 - 0_{t,5}) = (1 - X_{t,3})(1 - 0_{t,5})$$

and generally,

$$X_{t,g} = (1 - X_{t,g}m_n, \ldots - X_{t,g}m_0)$$

for the highest grade, and, therefore,

$$X_{t,g} + X_{t,g}m_0 + \ldots + X_{t,g}m_n = 1$$

and where n + 1 is the number of grades. To determine the number of people retained, NR, in any given year for any given grade, take

$$NR_{t+0,g} = r_{t+0}\, X_{t,g}\, N_t - P_{t,g}(\pm)A_{t,g}$$

where r is the retention rate, X is the proportionality factor, N is the number of men, P is the total promoted out, and A is the number transferring into or out of regular status from or to reserve status. This equation is the law of motion of the model, to use the terminology of this report.

This TOPLINE model was designed to assist in analyzing long-term objectives and has been used through the trial-and-error procedures of varying input parameters to establish a hypothetical objective force distributed over grade by year of service. This utilization is the only form of "optimization" the model offers. Several hundred runs may be necessary to reach a successful combination of policy decision variables. Fortunately, because of its aggregate nature, computer cost per run is minimal and such heuristically iterative usage is feasible.

As we have seen, input to STATIC TOPLINE consists of policy variables such as accessions or promotion opportunities. Retention rates are not considered decision variables, although they are conditional on the source of commission and the component. It is important to note also that retention rates are currently independent of grade and are dependent on year of service only.[1] Promotion opportunities are among model input variables and constitute a policy decision by personnel planners. Promotion opportunities can be differentiated depending on the type of promotion (e.g., captain to major), the rating (e.g., pilot), and year in promotion zone (years from eligibility to force-out). The planner makes implicit behavioral assumptions when he assigns values along these dimensions. Variable promotion opportunity of a limited nature is made possible by constructing three main distribution matrices and computing separate values for pilots, navigators, and nonrated personnel. No explicit assumptions about human behavior are made in the model, with perhaps one exception. If a man is bypassed on promotion, he is more likely to retire at 20 years than is a man who is promoted. An allowance is made, therefore, to reduce the number of men forced out.

[1] A limitation found in all personnel models discussed in this report. Work is in progress at Rand, however, that will permit retention rates to vary with promotion opportunity. See Section on OGLAMOD and OFPM.

DYNAMIC TOPLINE MODEL

DYNAMIC and STATIC TOPLINE were designed to assist with the same planning problem. Accordingly, DYNAMIC TOPLINE [34] is a grade management model employed to arrive at an optimal distribution of Air Force officers over years of service. The models differ chiefly in the distinction between dynamic and static. DYNAMIC TOPLINE is an unusual dynamic model, however, because most dynamic models are used for short-term planning and not for projecting the long-run consequences of implementing proposed policy.

DYNAMIC TOPLINE is a simple deterministic transition model in which planning factors are used to age the force yearly. Unlike STATIC TOPLINE, time is a major factor in projecting the force structure, allowing planning factors such as number in a state to change from year to year. Like STATIC TOPLINE, the dynamic model aggregates the force into cells using the same characteristics. Also like STATIC TOPLINE, the model does not attempt to incorporate behavioral assumptions. The model is subject to limitations in two main areas: retention, which is independent of grade in both TOPLINE models, and promotion. Promotion is assumed to be equal for any member in given grade irrespective of specialty or other requirements. Because promotion is assumed to be uniform (sometimes called equitable), sensitivity analysis on this key policy issue is precluded.

Besides producing annual estimates of the force over grade by year of service for each "cell" over the planning horizon, the model also estimates costs of the force, consisting of base pay and allowances, incentive pay, retirement pay, and procurement, training, and initial accession costs. These are computed directly from average pay or cost rates for each category.

The exercise of the model begins with an inventory of officers from the Uniform Officer Record and groups them into cells. The force is aged by applying retention rates (empirical base for FY 1966 through FY 1968) along with other policies and planning factors that may reflect peculiarities of the year in simulation. Regular officers twice passed over are forced out, according to policy. The model also calculates annual losses due to separations and retirements. As the force is aged each year, long-range projections are recomputed and updated. Allowances are made to account for nonaugmentation (officers not changed from reserve to regular) and suspension from flying status, as well as promotions, procurements, augmentations, and costing. The mathematics is simple algebra.

MODELS IN OASD/M&RA

The Air Force was an innovator in personnel modeling, which has now been taken up by all the services. As a result of a directive from the Secretary of Defense in 1972, more intensive DoD efforts in long-range manpower planning have been undertaken through the Office of the Assistant Secretary of Defense, Manpower and Reserve Affairs (OASD/M&RA). That office has been interested in systematic personnel management since at least 1968, however [16, p. II-1].

The TOPLINE models were developed to solve officer distribution problems specific to the Air Force and to assist in an overall effort to incorporate a systems approach to Air Force manpower management. Many of the modeling techniques that evolved during this effort, however, can be used in models developed in differ-

ent management contexts. Models used in OASD/M&RA employ some of the basic Air Force modeling techniques, but have somewhat different purposes. This section describes three models used by OASD/M&RA. Two of them grew out of the Air Force modeling effort. DOPMS [16] is similar to STATIC TOPLINE, while DEMOS [10] is based on TOPCAP [11]. TOPCAP is the TOPLINE model designed by the Air Force for enlisted force analysis. Because DEMOS incorporates most of TOPCAP's features, we have omitted discussion of TOPCAP in the TOPLINE section. A third model, NRETIRE [6], originated in the Office of the Secretary of Defense.

DOPMS: Officer Force Simulation Model

Manpower management interests in the Office of Manpower and Reserve Affairs (M&RA) are service-wide and financially oriented. Consequently, while DOPMS (Defense Officer Personnel Management System) is basically an officer grade management model, it has wider applicability than the TOPLINE models. Unlike the TOPLINE steady-state model, DOPMS includes procedures that cost the force. The model is a long-term planning tool that produces hypothetical force profiles and costs of the total end strength. Furthermore, unlike the TOPLINE model, it offers greater flexibility in the way retention rates and procurement sources are defined.

The Officer Force Simulation Model is a deterministic steady-state aggregate model. To facilitate service-wide applicability, a dimension that aggregates the force is included in the cell characteristics. The service-specific attribute is called a management category, so personnel are grouped by (1) year groups; (2) grade; (3) component; (4) procurement source; and (5) management category. These last two attributes uniquely determine a substructure upon which all computations are separately applied. Within the substructures, subsequent operations divide personnel into year groups, separate them into components, and finally distribute them into grades. To compute total force distribution and total force costs, the model sums over all substructures.

While this substructuring technique bears slight resemblance to STATIC TOPLINE's method of dealing with aggregation, TOPLINE's real contribution to DOPMS is the "smear technique." DOPMS uses a modified version that, in line with its overall broader applicability, permits a more flexible definition of procurement source.

The problem addressed is: Given (1) different sources of procurement such as service academy, ROTC, and officer candidate school, and (2) initial training rates that distribute the total procured from any single source into different categories, find the distribution of the initial procurement by categories and sources. Information input to this routine consists of (1) procurements, P_i, with sources given in order of increasing flexibility; (2) training flow rates from different sources, tr_{ij}; (3) total requirements, MREQ; and (4) retention rates. Using the flow equation, the mean system time is computed. Given p_i, procurement for source i, the number of people, n_{ij}, procured from source i in category j is found by multiplying the training flow rate tr by the number procured from source i:

$$n_{ij} = tr_{ij} \times p_i \, .$$

To find the total number of men in the system, m_{ij}, multiply the number in category j from source i by the mean system time, t_iJ:

$$m_{ij} = n_{ij} \times t_{ij} .$$

Now, it is possible that one of the sources does not flow into one of the categories ($tr_{ij} = 0$) yet the total requirements are not yet filled. Since sources are input in order of increasing flexibility, it is possible to alter the initial procurements, the initial training rates, and the initial distribution over source and category. The procedure does this by redefining these values based on the difference between the computed and the required total number of men in the system:

$$n'_{ij} = (m_{ij} - m_{REQ})/t_{ij}$$

$$p'_i = \sum_{j=i}^{j=k} n'_{ij}$$

where K is the total number of categories. Rates are then redefined,

$$tr'_{ij} = n'_{ij}/p'_i \; .$$

This procedure is repeated, each time using the difference between the current and previous computed values of total men in the system, e.g.,

$$n'' = (m'_{ij} - m_{ij})/t_{ij},$$

until total requirements are filled. This modification of the smear technique avoids an expensive iteration procedure.

A second area of interest is the way retention rates are obtained. The model accounts for differences in retention rates by the following characteristics: (1) source; (2) category (service or subservice); (3) augmentation status; and (4) promotion status. The resulting rates are referred to as additive loss rates; they consist of:

1. Residual loss rate, set by category and applied over all year groups. It is the only loss rate applied during periods of commitment.

2. End of obligation loss rate, set by source and effected for three years at the end of initial commitment.

3. Nonpromotion loss rate, set by grade (01-05) and applied during list eligibility year until force-out year.

4. Nonaugmentation loss rate, set only for reserve commission source.

After the additive loss rates are summed for each cell, the total retention rate is computed for each cell. Retention rates are taken over distributions in previous years in the component dimension and in the grade dimension to get a net retention rate by grade and by component. The ratio of the lower to higher value from the two dimensions forms an adjustment factor, used in recomputing retention rates.

These recomputed rates are employed to determine the number retained from one year to the next.

Although there are similarities between *STATIC TOPLINE and DOPMS*, DOPMS branches out into different areas. First of all, the DOPMS main computational array is not determined by promotion opportunities, so no single decision variable drives the whole system. By means of the additive loss rates technique, augmentation, promotion, length of commitment, and residual losses variously contribute in importance as decision variables. Secondly, because of the DOPMS variable procurement source algorithm, more decision variables are available to the planner in accessions policies. And, thirdly, the DOPMS treatment of retention is more comprehensive because retention is dependent on grade as well as component and procurement source.

Output of force profiles is displayed by component (reserve or regular) and grade over years of service. Unlike STATIC TOPLINE, DOPMS estimates costs of the force. Costs are based upon procurement, training, base pay, social security matching, death benefits, retirement, voluntary or involuntary separation, and contract bonus. The costing part of this model is supplemented by output from a dynamic retirement model also used in OASD/M&RA.

Of course, several assumptions made in DOPMS limit its range of applicability: (1) equitable augmentation (not service- specific); (2) equitable promotion; (3) no lateral flow; and (4) no lateral entry (closed personnel system).

NRETIRE AND DYNPCM: Dynamic Personnel Costing Model

NRETIRE is a modified version of DYNPCM [21], a dynamic personnel costing model designed to assist in a study of the military retirement system published in the *First Quadrennial Review of Military Compensation* in March 1966-January 1969. NRETIRE is used in M&RA to supply retirement cost figures used in DOPMS and to compare the present retirement system with suggested alternatives. In deriving retirement compensation costs, DYNPCM also projects the force, produces annual disbursements, and breaks total compensation down into its components. DYNPCM's *raison d'être*, then, is to serve as a cost planning model. NRETIRE uses the retired pay factor and is specifically concerned with the cost of nondisability retirement.

NRETIRE is a dynamic projection model. Its output is more predictive than ideal. Accuracy of its projection is of course limited by the representativeness of the input variables. Besides the transition probabilities based on (1) attrition rates and (2) mortality tables, the inputs include (3) an active duty force distribution; (4) average force size; and costing variables such as (5) basic pay table; (6) separation and equity pay; (7) peripheral pay; (8) wage growth and Consumer Price Index factors; (9) retirement annuity; and (10) Social Security data.

There are two facets to this dynamic procedure: (1) The active duty force is projected from a given known total force strength and a given distribution over years of active service. A constraint on procurement is set to maintain total average strength equal to the initial year level. (2) The force is aged by simulating losses, retirements, and procurements and is updated yearly. Losses and retention rates have an empirical base drawn from the relatively stable years FY 1963, FY 1964, and FY 1965, prior to the Vietnam War. The nondisability retired population is

projected. The cumulative retired population, fed out of retirements from the active force, is also aged annually by applying expected death rates. Future salaries and retirement contributions, and their appreciation, are calculated. Using the salary in the year any given man retired, his retirement schedule is calculated to include cost of living and, if necessary, the retirement Social Security offset.

Like DOPMS, NRETIRE offers special treatment of loss rates. For aging the force the planner can alter the model by initiating one or two assumptions concerning attrition.

In the first case, he can assume future attrition will be stable, so the number of people on active duty, $N_{t,j}$, for any given fiscal year j in year of service t is determined by the following relationships:

If K is the total number of different kinds of attrition and i is the number of completed years of active service, $A_{k,i}$ is a k-type loss rate in YOS i. The total number of losses is the sum, NL,

$$NL_{tj} = \sum_{k=1}^{k} A_{kt} \cdot N_{tj} ,$$

and the number surviving to the next year is

$$N_{t+0,j+0} = N_{tj} - NL_{tj}$$

The law of motion is more complex under the second optional assumption. In this case, the planner may assume attrition rates will vary. Of the various attrition rates, it was believed that separations and retirement for nondisability would be most sensitive, i.e., would yield the most information on alternatives in force structure for the planner, so only these are allowed to vary. Relationships are altered to consider a change of attrition rates during specific years by introducing special attrition rates $SA(j)_{kt}$ as a function of the fiscal year under consideration, so in addition to the nonvariant losses from $k = 3$ to K, there are special losses for attrition types $k = 1$ and 2. Hence, the survivors to the following year are

$$N_{t+1,j+1} = N_{tj} - \left(\sum_{k=3}^{K} A_{kt} \cdot N_{tj} + \sum_{k=1}^{2} SA_{kt}(j) \cdot N_{tj} \right)$$

The personnel planner can study, by calendar year, the distribution of the active force by years of completed service and separation from active duty. A table can be compiled showing annual calendar-year disbursements by years of completed service broken down by the components of compensation: basic pay, equity pay, readjustment pay, retired pay, Social Security offset, etc.

DEMOS: Defense Enlisted Management Objectives Simulation Model

The last M&RA model surveyed, DEMOS, is based on the Air Force model for enlisted men, TOPCAP. It is a service-wide grade management model that costs the force with special emphasis on promotion policies. It has the additional flexibility of being able to study individual specialties or groups of specialties within a service

as well as the service as a whole. The planning purpose of the model was "to provide the individual with an orderly career progression and a relatively stable career expectancy with the most successful achieving grade E-9 and retiring upon completing 30 years of service" [10, p. 2].

DEMOS is a steady-state model that projects and estimates costs of a force structure, with personnel distributed throughout 30 years of service. Basically, the model creates hypothetical grade and promotion structures described by length of service and pay grade. Additionally, for each grade, it allows the planner the option of solving for unknown policy variables, given combinations of known policy variables. Unlike DOPMS, DEMOS does not have a management category among its cells—in fact, it aggregates personnel only by years of service and grade—so service differences have to be reflected in input variables.

There are two kinds of input to this model: mandatory and optional. Mandatory input consists of (1) continuation rates by grade and YOS; (2) first year a person is allowed in a particular grade; (3) last year allowed in the grade; (4) percentage distribution of promotions into each grade by years of service in a specified promotion zone (used to determine what percent of total annual promotions to a grade are from each year group of the zone); and (5) retention year for each grade (year in which user can alter retention rates). Optional input consists of at least six different sets of given variables. Among the six run options allowed are: Given retention rate and promotion opportunity, solve for grade total and low year input (number of promotions into grade during first year of promotion zone). Another combination might be: Given promotion opportunity and grade total, solve for low year input and retention rate. With this policy flexibility, the planner can study the effect of different policy variables on costs and trained man-years.

This flexibility stems from the structure of the model. The fundamental equation of the model is

$$X_{gi} = R_{gi} \times X_{g,i}m_o + Z_{gi} - Y_{gi}$$

where X_{gi} is the number of people in grade g in YOS i, R_{gi} is the probability of remaining in service from YOS (i − 1) to i and not being promoted, Z_{gi} is number of promotions into grade g in YOS i, and Y_{gi} is number of promotions out of grade g in YOS i. The total number of people in a grade is

$$\sum_{i=s}^{h} X_{gi}$$

where s is low year and h is high year in the grade.

The algorithm works backward, beginning with the last grade, to determine the number of people in cells of the grade by year of service distribution. This is feasible because, this model being steady-state, promotions Z out of one state (g,i) equal promotions into the next:

$$Z_{gi} = Y_g m_{o,i} \,.$$

For the last state g, $Y_{gi} = 0$ for all i and therefore promotions-out is a known 0 value, and then Z_{gi} can arbitrarily be expressed as a direct proportion of any one of the promotions-in for a YOS, i:

$$Z_{gi} = k_i Z_{gj}, \text{ where when } i = j,\ k_j = 1$$

$$\text{and } kj > j > 1 \text{ are inputs.}$$

Once the Z's for the last grade are known, Y's for the previous grade are known. And given retention rates, proportionality constants (k), promotion-out, and total in grade, it is possible to derive promotions into the grade by solving the following sets of simultaneous equations:

$$
\begin{aligned}
X_{gs} &= Z_{gs} - Y_{gs} \\
X_{g,s+1} &= R_{g,s+1} \cdot X_{gs} + Z_{g,s+1} - Y_{g,s+1} \\
&\;\;\vdots \\
X_{gh} &= R_{gh} \cdot X_{g,h-1} + Z_{gh} - Y_{gh} \\
T_g &= \sum_{k=s}^{h} X_{gk}
\end{aligned}
$$

where T_g is total in grade g.

Given this basic framework, the flexibility of the model is evident. For example, the equations make it possible to derive the promotion opportunity PO_g, the probability that by the end of the zone an individual will be in the next higher grade. Let αZ_s be first-year promotions into a grade. Each of the equations can be rewritten in terms of Z, so α represents the sum of known retention rates and proportionality factors. If X_h is a number of people in a grade for the last year of the zone,

$$(1 - PO_g) = \frac{X_{gh}}{\alpha_h Z_{gs}} ,$$

or the probability of not being promoted is equal to the ratio of the number of people left in the grade to the number of people who would have been there if some had not been promoted. This relationship can be restated as $PO_g = \beta_h / \alpha_h Z_0$, where β is the sum of all promotions-out and corresponding retention rates.

Actually, DEMOS's overall treatment of promotions entails two modifications of TOPCAP. One of these iterative procedures or subroutines is called SEEK, which attempts to match a predetermined promotion opportunity to a promotion zone distribution that generates the given PO_g. The other subroutine, ADAPT, if given promotion opportunity, PO_g, and average YOS at promotion, finds promotion zone distributions that generate a promotion opportunity to match those given.

Three kinds of costs are computed: (1) static model costs, (2) investment model costs, and (3) full equilibrium costs. Static model costs are used to compare alternative forces; they represent the investment necessary to lease[2] a force the current year to cover procurement, training, and maintenance costs. Retirement costs are for those who retire this year; they consist of the amount necessary to invest to

[2] The term "to lease" is employed rather than "to buy" because leasing implies mere "use" for the period of the lease while buying implies permanent ownership.

cover retirement for every year until the retiree's death. The total investment is therefore

$$I = P_c + AP_c + R_c + FR_c$$

where I = total investment
P_c = procurement costs
AP_c = active pay costs
R_c = retirement costs for year in question.

$$FR_c = \frac{\sum_{m=2}^{n} R_m}{\sum_{k=1}^{n-1} (1+i)^k} \text{, future retirement costs}$$

where R_m are future retirement costs discounted by i for life expectancy of retirees. Various other costs are derived: multiple year costs, delayed lease costs, transition costs.

Depending upon the options specified, model output includes grade totals, promotions by grade, last and first year in grade, promotion opportunity, retention rates, retirement, and trained man-years. Among the costs displayed are total force, training, retirement, procurement, and maintenance. Another important output for M&RA policy analysis is cost per trained man-year. In evaluating the merit of different personnel policies, the planner uses these costs per trained man-year, so that both costs and trained man-year are functions of the policy variable under consideration.

TOPLINE MODELS

This section discusses models nonrigorously classified as TOPLINE-like models and their adjuncts. The impetus for the development of TOPLINE models was a desire for a systems approach to personnel management in the Air Force. Various models besides the previously discussed STATIC TOPLINE were and are being developed to assist in studying the effects of centrally managed and controlled conditions on the flow of Air Force personnel through the force structure. The final plan is reported in Volume 2 of the USAF Personnel Plan, [Officer Structure (TOPLINE) 1971] [24]. The specific models described here are DYNAMIC DOPMS [7]; two other models, OGLAMOD [13] and OFPM [14], of Rand origin; and OSSM [4], designed by Air Force Military Personnel Center (AFMPC). Briefly surveyed is the system of models currently used by the airman planning section.

DOPMS

As mentioned previously, the original STATIC and DYNAMIC TOPLINE models have been superseded. At the present time, STATIC DOPMS, discussed in

the OSD/M&RA section, is used by the Air Force in place of STATIC TOPLINE. This utilization is possible because of the versatility of the basic DOPMS model—the way management categories and procurement source uniquely define substructures. Additionally, a new dynamic model has been developed at Hq USAF called DYNAMIC DOPMS. This model supersedes DYNAMIC TOPLINE. Both of the DOPMS models are based on a better understanding of the officer personnel system derived from the initial TOPLINE models and are updated to reflect a more complete knowledge of the proposed Defense Officer Personnel Management Act [11].

DYNAMIC DOPMS

DYNAMIC DOPMS is the successor to DYNAMIC TOPLINE. Although it incorporates many TOPLINE features, it is different enough, especially in the treatment of promotion, to qualify as a separate model.

Like DYNAMIC TOPLINE, DYNAMIC DOPMS is a long-term grade management projection model. The typical planning horizon is ten years, although it can run for more or less than ten years. Unlike DYNAMIC TOPLINE, DYNAMIC DOPMS does not yield a hypothetical force structure and, although it is more predictive than the TOPLINE version, it must be stressed that it is a planning model used to test different policies and not to assist in short-term management decisions. Additionally, DYNAMIC DOPMS has costing routines that yield yearly and cumulative costs. In accord with the planning purpose, these costing routines do not produce budgets, but rather approximate periodic costs to allow planners another comparative means to evaluate policy changes. The model has additional flexibility: It can be used to plan under the current system or under the proposed DOPMS system, or can account for transitional effects between the two systems.

Like all dynamic models, DYNAMIC DOPMS begins with a force inventory taken from recent personnel (UOR) files. The (regular/reserve) force is aggregated into cells by (1) source of commission, (2) grade/DOR (Date of Rating), (3) rating, and (4) year of service. Members of this inventory are augmented (reserve to regular), suspended (from flying status), attrited, promoted, and then aged one year. New officers are procured and the cycle repeats itself until the terminal time period is reached. All these actions correspond to the law of motion found in DYNAMIC TOPLINE, but treatment of these policies differs in DYNAMIC DOPMS, primarily in modeling attrition and promotion.

With few exceptions, the augmentation and suspension routines are identical to those in DYNAMIC TOPLINE. The exceptions are: (1) Allowance is made to incorporate Defense Officer Personnel Management Act (DOPMA) augmentation rates, and (2) if the cell size is too small, lots are drawn using a random number generator to determine if all or none in the cell is augmented (suspended). Otherwise, the appropriate percentage of the cell population is augmented (suspended). Augmentation rates that determine the number are analyst-supplied inputs to the model.

Simulation of the other policies diverges more from the TOPLINE approach. In the attrition routine, three basic losses are accounted for: (1) normal attrition, (2) force-out of twice-passed-over captains, and (3) force-out of reserves as a result of the requirements of DOPMA augmentation policy. Part of the reason DYNAMIC

DOPMS is more detailed than DYNAMIC TOPLINE is that the basic losses are simulated monthly. Furthermore, at present, the loss rates are derived from the UOR file using the Air Force version of AID [35], and they are distributed over the months taking into account "seasonal adjustments." Loss calculations are performed monthly on a grade by grade basis, and once the number of vacancies in a grade is thusly determined, promotion can take place. Vacancies are determined by comparison of the current inventory with year-end requirements. These requirements are limitations set by grade based on the Officer Grade Limitation Act (OGLA), and are input to the model as a constraint.

Promotion is the most complex policy simulation. This complexity results from an entity called a promotion list, which causes the addition of a dimension—promotion cells—to the aggregation set of the main array. As mentioned before, one of the attributes upon which the force is aggregated is the grade/DOR dimension. The program has conversion arrays that allow DOR to be interpreted as rank and YGS to be interpreted as a promotion cell. Thus, while the promotion list is indexed by what appears to be a years of service dimension, they are actually years in the promotion stream, which may not correspond to the cell members' actual years of service. The promotion list holds the numbers selected for promotion from one grade to the next indexed by the year of service they will be in when promoted. Vacancies in a rank are filled from this list, starting with the earliest fiscal year of selection and the highest promotion cell from which the members were selected (date of rank seniority).

Members of the force are selected for promotion and entered in the promotion list by simulating the promotion board. Depending on the degree of attrition and, hence, the number of vacancies, the promotion board can meet any number of times a year, although initially it is scheduled to meet once a year. Those eligible for promotion are aggregated in promotion cells that correspond to years of service. Some of these years of service, in turn, qualify as years in the promotion zone. The number of selectees is computed by multiplying the promotion factor by the number in the primary zone, and the selected number is entered on the promotion list. The promotion cells are then aged one year. Those twice passed over for promotion are discontinued.

The whole inventory is aged one year; then accessions are accounted for from Academy, ROTC, and OTS sources. Some of these accessions are trained as pilots and navigators. A minimum value is set on the number to be trained to assure preparedness. This lower bound is another constraint on the system.

The costing routine [36] is detailed and accounts for costs derived from accessions, various kinds of training and pays, and retirement. The cost computation includes escalators to account for the rate of inflation. Retirement is treated as a once-paid annuity and is discounted to the year of retirement in the simulation, not to present dollars. Critical inputs to this model are the loss rates and requirements. The loss rates are important because they drive the promotion system. The requirements, the total force end strength, year-end grade requirements, and the lower bound on training are important constraints on the system. Given accurate loss rates and reasonable requirements, the decision variables that consist of promotion, augmentation, and training times and probabilities can be varied to test the viability of alternative policies.

OGLAMOD: Officer Grade Limitations Act Model

Most models designed to assist the Air Force in carrying out the management objectives established by its Personnel Plan (TOPLINE) are computationally independent of grade. OGLAMOD, however, treats grade limitations as an input and determines policies that maintain given numbers of men in each grade. It allows the manpower analyst to engage in long-term planning, given that a higher source has imposed grade authorizations.

Like STATIC TOPLINE, OGLAMOD is a steady-state deterministic model. It is also employed in long-term planning, and its results are hypothetical. Levels of aggregation defining a state are those common to all TOPLINE models: (1) component; (2) grade; (3) rating; (4) source of commission; and (5) years of service.

This model is atypical among the TOPLINE officer models because computations are performed backward from the last state (colonels and above with 35 YOS) and because output consists of policies that are usually input in the other models. The rationale behind this approach stems from the grade limitations imposed by Congress and the implications of operating at or near the actual limit. Inputs to the model besides grade authorizations are loss rates and flows. Because loss rates are an input, the backward calculation of force structure is possible. Application of loss rates yields the number of empty positions in the last grade, which in turn determines the number of people moving into the last grade. Because steady-state equilibrium must hold, this process can be repeated recursively until the procurements for the first grade are determined. The flow inputs consist of "flow ratios" and flow distributions.

The flow ratios specify the branching ratios relating the flows out of each state. After branching occurs, the distribution by YOS is specified by input flow distributions. Accordingly, the flow inputs set YOS distribution and ratios over combinations of these kinds of branching or transfers: losses, augmentations, rating transfers, promotions, and lateral movements through the officer structure. (Augmentation denotes advancement from reserve to regular status.)

Because of the aggregate property of the model, the flows are applied to a proxy for grades i called categories. Categories $C_i(t)$ are functions of years of service, t, where each category is a unique set of the other attributes in the aggregation set. For instance, the total number of men in a cell i at any given year t is:

$$C_i(t) = \sum_{j=1}^{J} X_{j,i}(t) \cdot T_j - Y_i(t)$$

where J is the total number of distinct kinds of transfers, including lateral movements, promotions, augmentations/promotions, or augmentations; where $X_{j,i}$ are different distributions of these transfers; where T_j is the total number of men affected by these transfers; and $Y_i(t)$ is the outward movement for the grade categories by YOS t. The T_j's are defined in relationship to flow ratio inputs and, along with equations for the C_i's, form a set of simultaneous equations to be solved. The total grade authorization for any category i is

$$G_i = \sum_{t=1}^{35} C_i(t)$$

Output from this model allows the planner to study projected inventories of officers by year of service and grade sorted on any of the cell attributes. Detailed officer flows are also given showing flows into and out of a state along with the total in the state. Other outputs which constitute a personnel policy in the TOPLINE sense of the term are given: rating transfer, loss, augmentation, and promotion rates.

As mentioned previously, OGLAMOD is unusual in generating values of these decision variables. This result is possible because OGLAMOD has a complementary model which assists in providing the rather complex input. OGLAMOD's complementary model is COFPM, the Constrained Officer Force Progression Model.

These two models can be regarded as a single two-stage model in which the two stages serve as testing grounds for each other in the personnel planning process. There is still interaction between model and user that requires decisions based on the planner's expertise, but more of the counterintuitive or complex calculations are left to the interaction between the models. (Work in progress at Rand interfaces these two models with a third model that varies retention by promotion opportunity.)

COFPM: Constrained Officer Force Progression Model

Because of the two models interface, the Constrained Officer Force Progression Model is similar to OGLAMOD in the degree of aggregation and the definitions and identification of flows between states. They differ in the kind of input, the direction in which calculations are made, and the treatment of promotion.

COFPM requires four manpower constraints: (1) size of total officer force, (2) size of regular officer force, (3 and 4) number of rated personnel that hold the rank of lieutenant colonel or below, along with several decision variables to control career reservists (career promotion opportunity, number of career reserve selectees, and total career reservists). Additional inputs consist of (1) annual accessions; (2) loss rates and policies; (3) augmentation rates and policies; (4) training rates and policies; (5) promotion phase points; and (6) promotion opportunities and policies. These last inputs are especially important because COFPM's detailed treatment of promotion is based on the notion of a promotion phase point, the one year out of the four years in the promotion zone when most promotions take place. While the definition of promotion opportunity is similar to that in STATIC TOPLINE, it is more complex in COFPM. It specifies and solves a set of simultaneous equations to allow for differences in promotion over the first (primary) zone and the second (secondary) zone. Beginning in year one, when the number in state one is the number procured (promoted), the model computes losses, rating transfers, augmentations, and promotions pertaining to each state.

This procedure is further complicated by the imposition of requirements. They are met by sequentially building substructures determined by source of commission that work through the different policies appropriate to a given level of aggregation. The order followed is ROTC, Academy, and OTS. In effect, the requirements are satisfied by iteratively adjusting (increasing/decreasing) end of obligation loss rates (which may not fall below an input lower bound).

The value of COFPM to a personnel planner is its ability to locate irregular officer flows on a microforce level. The cost of such detail, of course, lies in the

complexity of calculations and the input/output routines. The planner can study the distribution of officers by component, rating, YOS, or source of commission, and the flows into and out of each category. Additionally, COFPM displays losses, rating transfers, augmentations, and promotion numbers and rates by YOS format over all combinations of cell characteristics. Also, it gives the distribution of promotions and augmentations necessary as basic data input for OGLAMOD.

OSSM: The Officer Structure Simulation Model

The Officer Structure Simulation Model is actually a family of three models developed by the AFMPC. Unlike the other TOPLINE models, which are mainly grade management models, the OSSM group is designed to look into other problems of career management and force composition such as Air Force Specialty Code (AFSC) assignment and management, manning by AFSC, and training requirements. Two of the component models are long-term planning tools employed to analyze trends in the officer force: Total Force Aggregate Model and the AFSC Analyzer. The third, called the Entity Model, provides short-term projections. Because they can be used to estimate costs, these models are also useful in budget planning.

The three models in OSSM are dynamic. Each is designed to meet specific needs of a planner, and each illustrates how different objectives direct the design of inputs, structure, and outputs of a model. These submodels estimate the configuration and cost of the existing force at some future point in time. They are predictive models looking at personnel actions and policies such as accession, training, education, integration (augmentation) (reserve to regular status), promotion, reassignment, attrition, end of obligation losses, separation of career officers, and retirement. Two of the models are deterministic and aggregate, resembling DYNAMIC TOPLINE, but they break down the officer force by AFSC as well as project the total force. They are used for long-term trend analysis. The Entity Model is stochastic and follows individuals through the system. It is designed to give greater accuracy in short-term planning. Both kinds of models use the same data base, generated from empirical cases, in the form of probabilistic transition matrices found in a Prediction Factors Table. These elements include (1) loss rates (the only data used from the table in the Entity Model); (2) promotion rates; (3) lateral transfer rates; (4) integration rates (transfer from reserve to regular component); and (5) accession/distribution rates. The last four are used only by the aggregate models.

Entity Model. As the name indicates, the Entity Model does not aggregate personnel into cells that are defined by characteristics. Instead, it works with the individual record of each officer in the system, and its predictions are therefore more specific. It does not model an average behavior as other TOPLINE models do. This model selects characteristics from the data file appropriate to the decision being made and incorporates behavioral assumptions in a closer mapping with the real world than that found in the other models.

To simulate real world actions, the model uses a random number generator when selection or decisions appear to be out of the rational control of the planner and in the domain of real world contingencies and variance in choices or chance happenings. Because of this design element, the Entity Model is stochastic rather than deterministic. When decisions are within the purview of the personnel system, the model follows the logic and rules corresponding to given policy actions.

To allow for greater flexibility in use, this model has a modular construction. Each module simulates a policy action or decision. Combinations of policies can be studied by adding or deleting modules. The standard procedures are promotion, accession, and losses, but short-term drastic policies such as an RIF (Reduction in Force) can be simulated, as well as two long-term processes—integration and assignment.

To illustrate the simulation process found in the Entity Model, the following text briefly outlines the promotion module's procedure: First, eligibles are selected. If a record has proper grade, sufficient time in grade, and correct promotion category, it is tagged. All records are then sorted by Officer Efficiency Rating (OEF) mean.[3]

(The designers suggest that a regression analysis be incorporated here instead of using the OER mean to predict who will be promoted.) At the predesignated time interval, the "board" selects promotees. Second, the procedure sets quotas for each year in the promotion zone. Third, promotions are set to correspond with quotas, and finally, the actual change of rank is performed.

Outputs from the model include: (1) AFSC management and assignment actions; (2) the manning plan, a quarterly report predicting assignment actions for three years in the future; (3) force profiles (similar to DYNAMIC TOPLINE); (4) OFFICER TPR (trained personnel requirements), an annual report matching force requirements by career field against predicted gains, losses, and other flows; and (5) any user-supplied subroutine that calls upon output files written on tape by the model.

Aggregate Models. The two aggregate models are the Total Force Aggregate Model and the AFSC Analyzer. Both are predictive, deterministic transition models that use transition probabilities to project from one state to the next. These models also have modular construction so that one policy or any combination of policies can move personnel through the structure. The Total Force Model aggregates by component, source of commission, grade, rating, rated job category, and year of commissioned service. The AFSC Analyzer has three optional levels of aggregation. All three apply to rated AFSC, and one applies to supplement AFSC as well. All the aggregation levels group by component, major command grade, and rated job category, and variously use years of commissioned service, years of rated service, or total flying hours as the last dimension.

The probability of being promoted depends on grade and years of commissioned service. The values may be set by input or defaults from historical data. Additional flexibility is achieved by letting the planner fix one of the three variables and study the effect of varying the other two. One may fix the promotion phase point or grade totals or promotion opportunities. Force-outs are also set either by input or default.

The aggregate models estimate costs of the force in nine major categories: salary; miscellaneous pay categories (medical pay, hostile fire pay, etc.); procurement; initial flying training; advanced flying training; technical training; education; and retirement.

The Air Force Enlisted Management System

Although the kernel of the computer-based airman planning system, DEMOS,

[3] Each officer is rated yearly by his commanding officer on a scale from one to ten on various attributes relevant to his work.

has already been discussed in the OSD/M&RA section, some attention is given here to the specific application found in the Analysis Branch of Personnel Plans at Hq USAF [11]. Like static DOPMS, the DEMOS Model is versatile in its applicability. In fact, in the system of models used for the enlisted force, DEMOS has two different applications. In the one case, it is used for career field management and, in the other, it is a grade management model.

The system's initial concern is to determine the skill mix within career fields. These derived skill level[4] requirements are then interfaced with total force grade management objectives.

Input to a skill projection model is the total force size. This model outputs skill-level 7 and 9 authorizations. These requirements, in turn, are input to a version of DEMOS modified to operate on career specialties rather than grades, along with loss rates (given by AFSC and year group), and rates on the upward movement of skill-levels 7 and 9. This DEMOS model gives the career force configuration that, in turn, is input to another DEMOS model along with loss rates and total force size. Outputs from this second DEMOS model are a grade by year of service distribution and promotion opportunities.

Three other key models complete the system. The Topgrade model uses DEMOS's distribution and promotion opportunities to separate the grade/YOS distribution into Career Progression Groups. (This term refers to a class of AFSs that have historically exhibited interaction.) A linear program optimization model minimizes the difference between output from this system of models and exogenous manpower authorizations. And, lastly, a dynamic program is used to age the current inventory and test these policies in a more prescriptive vein.

ARMY MODELS

Manpower planning models for the Army have evolved rapidly during the last four years. Since 1972, several new models have been developed and manpower planning has been intensified because of the advent of the All-Volunteer Force. To establish requirements for the objective force, the Army has used the static model DEMOS previously described. Of the many concerns in Army manpower planning, both career field management and total force strength have been stressed. Because of the interest in these areas, three models relevant to these issues are surveyed here. The first is the Central Integrating Model—Officers (CIM-O) [3], an officer grade management model designed to evaluate differing policies as they affect end strength. The second is the Central Integrating Model—Enlisted (CIM-E) [8], which attempts to allow planners to study policies affecting total enlisted force strength and career field management within a single model. The last is the Automatic Interaction Detector (AID-E) [37], which predicts loss rates. (Although there is a complementary model for officers (AID-O), it is omitted from discussion here because of its basic similarity to the AID-E.) Accurate derived loss rates are essential because of the unreliability of historical rates. The Army faces a data problem, since the draft and the Vietnam War have rendered pre-1973 data meaningless.

[4] The level of qualification in an Air Force Specialty (AFS), a group of related positions, defined as (1) helper, (3) semi-skilled, (5) skilled, (7) advanced, (9) supervisor.

CIM-O: Central Integrating Model—Officers

Along with the other two models surveyed in this section, the CIM-O was completed (in 1974) as part of a two-year contract "to assist the Army in increasing the reliability of manpower strength and composition projection several years into the future" [3, p. 1]. This contract was granted by the Assistant Secretary of the Army, Manpower and Reserve Affairs, and the Office of the Deputy Chief of Staff, Personnel, to GE-TEMPO, the Technical and Environmental Management Planning Operation of the General Electric Company.

CIM-O is a dynamic predictive model with a five-year or less planning horizon. It is not used for long-term planning. Its planning objective was to give short-term accurate strength configurations of the force that would allow planners to study different policies relating to end strength, losses and gains, and promotion. It does not cost the force or provide budgetary information on retirement.

Because predictive power and accuracy were given priority in design considerations, CIM-O is an entity model that identifies each member of the officer force by fifteen data characteristics. As a result, the model requires extensive data management capabilities to order and select the basic inventory, which is drawn from the officer master tape records. An obvious disadvantage in these models is their extensive processing of data files, which entails long run-times and the necessity of having expertly trained personnel to maintain the system.

In the policy simulations that constitute the model's law of motion, both deterministic and stochastic methods are utilized, so the model is categorized as stochastic. In terms of this and the other classifying attributes previously mentioned, the CIM-O is most similar to the OSSM Entity Model.

This similarity also extends to modular construction. The CIM-O consists of four main procedures: (1) An editor controls data file management to generate the begin inventory from master records. (2) The rates and constraints module holds all input, except the begin inventory, to the policy simulator. This input module allows user interface with the system and permits interactive submittal of decision variables as well as historical rates, authorizations, or other constraints. This phase of the model is user-oriented and provides diagnostic messages before execution if an input error occurs. (3) The simulation module actually applies the policies to the officer inventory by first computing losses, then gains, then promotions. It finally ages the force one year by incrementing the time-variant variables that identify force members. (4) The report writer is an output module that offers up to 130 options. Each of these summaries is indexed by grade and other of the various identifying variables. Generally, four classes of output exist: end strength, losses, gains, and promotion.

Input to the policy simulation includes loss rates (given by loss causes) that may be derived from the Automatic Interaction Detector loss prediction model for the officers. Also necessary for loss projection are analyst-supplied data on reduction in force. Accessions input consists of requirements—Authorized Branch End Strengths—and analyst-designated "fenced branches," those branches[5] whose requirements must be filled, along with desired and minimal percentages of require-

[5] Branches are organization divisions of the Army by occupational areas that control assignments and other personnel matters. They include AD (Air Defense Artillery), CH (Chaplain), IN (Infantry), WC (Women's Army Corps).

ments acceptable in the other branches. Promotion and integration (reserve to regular) selection rates are given by simulation year and grade for both reserves and regular Army along with grade end strengths.

In the loss routine, the records are first eliminated on the basis of information that absolutely determines losses (e.g., RIF). Those records remaining are then processed for probabilistic modeling of losses. For each loss cause (voluntary, mandatory or disability retirement, discharge, promotion passover, etc.) a probability exists in the loss rates file that is uniquely determined for each officer by the set of attributes (fifteen variables) peculiar to that officer.

Procurement is interesting because it is determined by branch. An iterative procedure fills the branches by priorities, yet maintains an ideal distribution of procurements over the lower priority branches. The number to be procured is determined by comparing the inventory after losses with the Authorized Branch End Strengths.

The constraint operating on promotions is Authorized Grade End Strength. Again, the inventory after losses and gains is compared with these requirements to compute the number of vacancies. Promotions are computed by zones (primary, above, below) by first computing the total to be promoted (given percentage for the zone times vacancies), then adding numbers in a grade by monthly increments decreasing from the last month in the zone until the required number is met. This procedure is possible because members of the inventory can be identified in a grade by time (months) in grade array.

CIM-E: Central Integrating Model—Enlisted

In 1974, the Central Integrating Model for the enlisted force (CIM-E) was developed by GE-TEMPO under a two-year contract from the Office of the Assistant Secretary of the Army, Manpower & Reserve Affairs. The model addresses the integration of two key problem areas in the Army manpower prediction system: enlisted strength and career field management planning. While the first is mainly concerned with total manpower in the force, regulated within constraints imposed by DoD and Congressional directives, the second is concerned with a balanced composition of grade, skill level, and years of service within the force structure. Realization of these operational objectives independently can lead to conflicting policies. Accordingly, CIM-E attempts to study the effects of total strength constraints on grade and years of service, as well as skill level. It also projects cost of the force so alternative policies can be evaluated in regard to budgetary constraints.

The manpower planner can manipulate several decision variables. To control the objective force, the planner supplies total strength and grade constraints distributed by grade and years of service. The planner can also supply reenlistments, losses, procurements, returns to military control, other gains, demotion rates, promotion rates, and cost factors. To study the effects of alternative values for these decision variables, several kinds of output are available to the planner: (1) Summary of losses, gains, promotions, demotions, and enlisted strength for the total force. These are broken down by grades in the first-term force. (2) A distribution of the total force by grade and time in service. (3) The objective force distributions by grade and time in service. (4) Group shortages by grade. (5) Gross cost per year for the total force. (6) Summary of all projected promotions and demotions.

Another feature of the model allows this output to be for selected subsets of the original force inventory. These subsets are sorted by characteristics of each individual in the Enlisted Master File. Variables such as sex, mental group, race, civilian education, and career management field (CMF) can be excluded or included in different combinations. Hence, if the career field management planner wants to study members of certain CMF with a given educational level, he would specify this requirement. Policy variables are then applied to the force included in the selected group.

In order to understand this capability, it is necessary to examine certain structural properties of the model. CIM-E is mainly a dynamic projection model that ages a force anywhere from one month to five years. It begins with an extract from the Enlisted Master File. This sample provides the initial inventory and contains static and dynamic variables. The static variables are those that can be sorted to give subgroups with specified characteristics (e.g., sex, race, CMF). The dynamic variables aggregate personnel and change over time; these include grade, time in service, time in grade, and time to expiration of time in service. In their role as levels of aggregation, these dynamic variables are dimensions in the inventory matrix. Each member of the force (or subset thereof) is indexed by these variables. To account for differentiating between first-time personnel and reenlistees, the matrix is divided into two sections. Time units in the section for first-termers are in months. Units for reenlistees are in years. All calculations involving reenlistments, losses, procurement, promotion, or demotion are performed on this main computational array.

As a supplement to the dynamic projection, the complete model also projects an objective or ideal force. The initial distribution is given for each month by grade and time in service, and attempts to incorporate future and current constraints on size and composition, beginning with the monthly authorization drawn from the central management file. If a subgroup option is employed in the dynamic projection, the ideal projection's population is scaled down by a percentage for each static variable. The planner specifies other values such as trainees, transients, patients, prisoners, and students so the total strength is complete. The analyst may also supply additional constraints on total strength. The objective force information is used to determine shortages and procurements by comparison with the inventory matrix at various steps in the dynamic simulation process.

The simulation procedure consists of a set of steps in which numerical values for personnel are shifted along the various dimensions of the inventory matrix. Reenlistments are calculated by applying rates to each cell of the array, summing, and adding the total to the inventory. Losses are then computed and subtracted from the inventory, and procurements are computed by determining the difference between the projected objective force and the inventory adjusted after losses. While demotions are computed using the rate file, promotions are calculated by comparing against the projected objective force by grades after demotions and losses have been subtracted from the inventory. Open cells are filled by eligibles from the next lower grade. Finally, the force is aged one year by incrementing all cell members by one. This total simulation is for one month, so the procedure must be iterated as many times as necessary to fulfill the projected time period requirements.

The rates used by CIM-E are created by another model developed by GE-TEMPO for the Army. Because of its relationship to the CIM-E and also because it is an interesting example of a strictly predictive model, a discussion of it follows.

AID-E: Automatic Interaction Detector—Enlisted[6]

Automatic Interaction Detector for the enlisted force (AID-E) was developed by GE-TEMPO in 1973. It is part of a two-year project that began in 1972 called the Army Manpower Prediction System (AMPS). The purpose of the study was to develop "more useful and accurate projections of manpower strength and composition" [37, p. 1]. It was found that the Army's modeling effort was varied and decentralized. In order to integrate manpower planning, a model was needed that would produce a consistent and accurate prediction of loss rates in formats compatible with all extant operational models. AID-E was developed to meet that need.

AID-E is a strictly predictive, statistical, entity model that uses empirical data consisting of extracts from the Enlisted Master File (EMF) records and an extract from the Gain/Loss Transaction Files. These two sources are merged to form information needed to describe each enlisted man. The number of variables (43) used by the model is limited only by the information found in the data file called the Enlisted Historical File. By means of its statistical procedure, the model selects all predictive variables from the data file. While the variables usually used are drawn from the EHF records, it is possible to add exogenous variables, if a change in the state of the world should affect loss rates. For example, if the unemployment rate in the civilian sector should change or if war were declared, the model could accommodate these changes as variables in its predictions.

The statistical procedure used is called the Automatic Interaction Detector, which was developed by the Institute for Social Research at the University of Michigan [39]. It consists of iterations on a procedure referred to as "binary splits." On the first iteration, the population as a whole is considered. Pairwise sorts are done on the variables to separate the population into two mutually exclusive sets. Thereafter, the already formed subsets are in turn separated into subsets until the resulting subsets violate minimum values for variance and number within a subpopulation. If the variance and population are too small for another subpopulation to be formed, the whole procedure stops.

When population is sorted into two mutually exclusive sets, a subpopulation defined by this sort is a candidate for binary splitting if it has the larger of the two populations' total sum of squares. This value, TSS_k, is expressed as

$$TSS_{k_1} = \sum_{j=1}^{N_k} y_j^2 - \frac{\left(\sum_{j=1}^{N_k} y_j\right)^2}{N_k}$$

where k is a subpopulation, N_k is the number of observations in the subpopulation, and y_j is the value of the loss rate for each observation in the subpopulation.

In terms of the variables employed by the Army's AID-E, assume a split has been made on ETS (the number of months before term of service is completed) and another data characteristic, and the ETS subpopulation has the larger of the two variances. At this point the ETS subpopulation may be split on yet another characteristic, number of months remaining. For example, it may be found that the break maximizing the sum of squares condition on the ETS group k is between 13

[6] This model is based closely on a loss projection system previously developed by the Air Force [38].

and 14 months. Accordingly, two new subpopulations are formed: N_k, months remaining ≤ 13, and N_{k+0}, months remaining ≥ 14. A subsequent iteration may be on one of these newly formed subpopulations where the split falls on different values for grade. Of course, this procedure continues until the minimum conditions on variances and numbers of observations is violated.

As a result of this procedure, each person in the EHF falls into a unique subpopulation and has a set of descriptors because the partition consists of mutually exclusive sets. Every person, then, has a loss probability assigned to him. For this reason, AID-E is an entity model.

It is clear, then, that unlike the CIM-E this model does not represent a theoretical framework used to study the effects of policy changes. Instead, it is a predictive model used to give an accurate annual projection of loss rates. In test runs, the losses predicted by AID-E varied from actual FY 1973 losses by less than 1.5 percent and from actual FY 1970 losses by less than 3.5 percent. Output from this loss projection model can be in any format, so long as transformation from annual loss rates to other time periods is accounted for. It was designed to be compatible with any other model used to study manpower policy. The model also has analytical benefits. Because of the way AID-E groups personnel and because these subpopulations reflect changes in the composition and attributes of the force, it can locate problem areas and pinpoint causes of losses. In fact, intermediate output from the model is a set of mutually exclusive descriptors of individual characteristics along with probabilities of loss for each descriptor. With this information, the manpower planner can more intelligently evaluate policy changes and place greater confidence in models which use the output to study the effects of policy change.

One possible impediment to widespread application of the model is the computer cost of exercising it for large data sets. A computer run for each loss category requires knowledgeable personnel to assemble the data and 15 to 20 minutes of CPU time (IBM 360/50) for execution. The complete computer execution for all loss categories and all Army models that are provided with loss rates requires 6 to 9 hours of CPU time. The originators of the model argue that such costs are feasible when runs are infrequent (once or twice a year) and when these costs are weighed against benefits.

NAVY MODELS

The Navy has been active in personnel research and systematic planning for a number of years. Their most ambitious effort is the ADSTAP system, one of the most important optimization models undertaken by the services. This section analyzes a component of this system, FAST [5], the nonoptimization projection model that interfaces with the current system's procedures. FAST models the Navy's enlisted force, while the second model surveyed, the CNA OPM [9], or Officer Projection Model, is a representative officer structure simulation, developed by the Center for Naval Analyses.

FAST: Force Analysis Simulation Subsystem

Under the direction of the Chief of Naval Personnel, the Naval Personnel & Training Research Center (NPTRC) was instrumental in laying the groundwork of

the ADSTAP System in 1971 [17]. NPTRC's main client for this work was the Active Enlisted Plans Branch (PER-A12) of the Bureau of Naval Personnel. This agency has responsibility for managing policies related to recruiting, training, promotion, losses, incentive systems, strength levels, and grade distribution of enlisted naval personnel.

Like most personnel modeling discussed in this report, ADSTAP was initiated to solve a specific problem and then led to the definition of other relevant research areas. The original problem was to optimize the ratios of various petty officers between grades as well as ratios between petty officers and personnel within grades. The study then grew to an analysis of the promotion system, and finally resulted in FAST, the more encompassing projection described in this section.

The management objective for FAST is "to initiate and control the flow of personnel through the system to ensure sufficient personnel resources in the various occupational specialties or ratings in each pay grade of these ratings and at specific points in time" [39, p. 7]. FAST is fundamentally a career field management model that attempts to balance grade structure within an occupational area. Implicit in the design and application of this model is the assumption that requirements and constraints are imposed on planning and management decisionmaking from higher policymaking levels.

FAST is a dynamic predictive model that simulates grade structure within ratings or groups of occupational specialties in the U.S. Navy. Because it uses a random number generator to distribute personnel over years of service, it also has stochastic features. Personnel are variously aggregated by rating, grade, and length of service at different stages in the simulation.

The model simulates three procedures: losses, gains, and advancements. The routine predicts losses and gains that are applied to the main array or inventory in the advancement routine. Interaction of these variables with cells of the advancement inventory constitutes the model's law of motion.

FAST's treatment of attrition and accessions is detailed and specialized. Losses are determined by empirically based rates, while gains can be derived from historical as well as analyst-supplied rates. Specific losses predicted are: (1) expiration of enlistment; (2) attrition; (3) retirement; (4) desertion; (5) USNR separations; (6) demotions. Specific prior service gains predicted are: (1) continuous service reenlistment (2 to 90 days); (2) broken service reenlistment (+90 days); (3) deserters returned; (4) USNR volunteers; (5) USN miscellaneous gains; (6) USNR miscellaneous gains. Non-prior-service gains or recruits are determined in the advancement routine by subtracting the total net inventory from end-year requirements. Some of these vacancies are filled by promotions, but those for the first year are accessions. All these kinds of gains and losses are computed separately for each cell in the matrix with 7 pay grades and 31 years of service that define a rating.

This separation means that each kind of gain or loss has a transition matrix containing appropriate rates that are applied to the individual grade/YOS for all populations of the given rating. These historical rates are derived from the Navy's comprehensive personnel file, which dates back ten years. To find the total Navy gains and losses, the values from each of these rating force substructures must be summed. After losses and gains are predicted, they are applied to the basic inventory to get the net population; vacancies are then the difference between the net population and the desired end population as given by the planner. Additional

complexities in the promotion system are simulated by FAST. For instance, Navy personnel must pass examinations to be eligible for promotion within a rating. The model predicts the number of people likely to pass these exams. In this way, both candidates for promotion and vacancies within a grade are accounted for. The lesser of the two values is the number promoted. The model also incorporates career ladders by branching within rating groups. The number of promotions in each pay grade are stochastically distributed over years of service within a grade to simulate the new distribution by grade length of service.

Output from this model is varied and gives the planner many options, including item-by-item specification of 75 different kinds of information necessary to evaluate policy alternatives. There is a variety of output options in exercising the model. Besides all the predictions from the attrition routine, the model gives strength by LOS, grade and rating, and the configuration of the force by rating and pay grade. The planner can determine if requirements were met by studying all information relating to ratings. More important, the planner can study the feasibility of alternative policies affecting requirements, promotions, and retention. It is important to note that FAST is part of the large MAD system and is designed to interface with ADSTAP data bases as well as other ADSTAP modules.

OPM: The Officer Projection Model

Originally conceived as part of the Accession and Retention Initiatives Study, OPM, the Officer Projection Model in its present form (1974), is a Navy Resource Study designed and developed by the Institute of Naval Studies at the Center for Naval Analyses.

"The model provides management with a tool for evaluating alternative promotion policies and retirement proposals, and for studying the interactions of officers end-strength, promotions, and accessions, and the cost of changes in longevity and grade structure" [9, p. i]. Special emphasis is given to modeling the complexities of the Navy officer promotion system. In our terms, OPM is a grade management model operating within budgetary constraints and the legal framework for promotion specifically outlined in Title 10 of the U.S. Code.

Theoretically, OPM can project the officer force for an extended time period, but it is best applied over 3-to-5-year planning periods, because during this time frame the budgetary planning needs are best met.

OPM is a deterministic dynamic model that aggregates the officer force. With the exception of its treatment of promotion, the aging procedure is straightforward and simple. Two kinds of data are necessary to operate the model. Required data consist of the initial inventory, continuation rates, and pay data. Policy variables consist of accessions, end strength, and promotion-related parameters.

A residual inventory is generated by applying continuation rates to the initial inventory. The inventory aggregates personnel by values along three dimensions: (1) rank (ensign to captain); (2) length of service or year group (1 to 30 or cohort year); and (3) promotion status (early, normal, failed). Continuation rates are required data that are usually set automatically. In the automatic case, initial continuation rates must be supplied for normal, fail-select, and force-out policies, but any further necessary adjustments to account for changes in promotion flow

points[7] and fail-select force-out points are done automatically. Additionally, any or all parameter values can be changed by supplying other data manually or by changing values through the interactive systems available.

An intermediate inventory results from applying continuation rates to the initial inventory. At this stage, accessions are determined by comparing the cells in the intermediate inventory (by grades) with year-end strength requirements. Accessions to the force are either the difference between the intermediate and end strength values or some minimum accession set by policy, whichever is larger.

Along with minimum accessions and end strength requirements, promotion parameters are part of the policy variable set. Policy analysis in promotion is carried out for normal, early, and late promotions. For normal promotions, the planner sets values for (1) the promotion rate (ratio of number promoted to number in the zone); (2) percent of end strength in each rank; (3) number in each promotion zone; (4) minimum promotions to each rank. If the planner overconstrains the system in establishing these values, a set of built-in priorities takes over to preclude infeasibilities. Early (late) promotion, "below (above) the zone," is determined by assigning (1) early (late) selection rate (the ratio of the number promoted below (above) the zone to total number promoted), and (2) year groups in which early (late) selectives are to be made.

The final inventory is costed using input data on base pay and compensation. The model can produce estimated costs of active duty, severance, and retirement pay. The output consists of (1) final inventory displayed by grades, LOS, and promotion status, (2) survival rates, (3) average basic pay, (4) retirees and separatees, and (5) costs incurred by retirees and separatees.

OPM's outstanding feature is its user orientation, as is evidenced in the automatic setting of continuation rates and in the procedure for overriding infeasible constraints on promotion policy variables. Many of the subroutines are interactive and conversational, allowing the planner many options in application and modification.

In many ways, the OPM is comparable to the OFPM developed for the Air Force. Both study officer promotion policy, with emphasis on setting promotion zones, flow points, etc., but their treatment is different. The OPM's treatment of infeasibility is to prevent it, while the OFPM gives detailed output so infeasibilities can be located within the system where they occur. Although both are grade management models, the OPM is dynamic, designed for short-term planning with budgetary information output. The OFPM is a long-term steady-state model yielding hypothetical results without any cost-estimating options. Both, however, put special emphasis on promotion decision variables and attempt to work within constraints imposed by a given promotion system.

[7] The last LOS for normal officers in the rank.

Appendix A

A REVIEW OF TECHNICAL ASPECTS OF DOD OPTIMIZATION MODELS

This appendix provides a brief technical description of the six optimization models discussed earlier. The notation their authors used for each of these models is simplified here to arrive at a common notation. Doing so unavoidably loses some of the refinements that the individual models have incorporated, but will not affect the description of the basic structure and optimization techniques.

THE COMMON NOTATION

Let vector variable x describe the state space, the number of men in each category (whether or not it be broken down as far as MOS, grade, skill, LOS, etc.). This variable may be a function of time t, so in dynamic models this would be expressed as x(t).

Let A be a *transition matrix* indicating the fraction of men in any cell moving to each other cell. The ith row containing the jth element, $a\beta_j$, would be the proportion of men in cell i moving to cell j in the next period. Matrix A may be a function of time and a function of decisions made that affect retention and the like. In general, the law of motion is specified by

$$x(t) = A(t) \times x(t - 1)$$

where initial conditions prespecify x(0). Accessions, $x_0(t)$, must also be specified. This is known as a Markov model.

Constraints on the number of men with certain characteristics—called requirement constraints—take the form of $C \times x \geq R$, where R is a vector of requirements and each row of C specifies with zeros and ones how the requirement is fulfilled. Similar constraints may be defined as equal, others as less-than-or-equal-to. A budget constraint is such an example.

Productivity is measured by a function S of x. If the model uses a linear production function, $S(x) = s \times x = \Sigma s_j x_j$, where s is a vector of productivity weights.

THE RAND MODEL

The state space descriptor vector x is defined to be the number of men in each of five different terms-of-service classes, each being four years long. The time variable t is removed from the notation since the model assumes a steady state. Aggregation was done for simplification and for developing the model for illustrative purposes. Accessions are a function of perceived pay as specified by a nonlinear supply relationship. Similar relationships exist to measure retention behavior at each reenlistment point. Perceived annual pay is a composite of the future expected

wages and retirement properly discounted; it is used as the basic determinant of accession and retention in developing x_0 and the state transfer matrix A. This set of pay variables constitutes the basic decision variables of the model and is called the policy.

The limited size of the state space and the simple flow among states make it possible to solve for the limiting states resulting from any policy:

$$x_0 = x_0(p_0), \text{ and } x_i = r_i(p_i) \times x_i m_0$$

where r_i is the retention fraction determined by the perceived pay p_i for term i.

Productivity is measured using either a Cobb-Douglas or a linear production function, S(x). The total annual sum of wages and retirement is subject to a constraint of the form $w \times x \leq B$, called a budget constraint. Wages and retirement pays are included in w, which is functionally related to perceived pay.

The objective is to choose a policy for perceived pay that will elicit accession and retention behavior as specified by the nonlinear supply relationships, so as to maximize the productivity rate S(x) subject to a single budget constraint $wx \leq B$. A nonlinear optimization problem results that is solved numerically by a search technique called gradient search, which moves up along the maximum slope from any good starting point. The optimization calculations are programmed in Fortran and several sets of input data and parameters are tested and reported. The algorithm converges quickly with the five decision variables currently used, and expansion of the approach to larger manpower systems is conjectured to be straightforward.

The average annual productivity rate chosen as the objective is shown to be a good approximation for the correct objective, which considers the total present value of the system. The model is placed in its decision theory context and shown to satisfy conditions that make the average productivity and cost rates relevant objectives.

THE ADSTAP SYSTEM

The state description vector in ASTATIC denotes men by LOS and pay grade in the steady-state environment. Historical statistics on loss behavior, attrition, etc., for each LOS-pay-grade cell are known and available as input in terms of a transfer matrix A. Movement from each cell is out of the Navy, to next-higher LOS at same pay grade, or to next-higher LOS and higher pay grade. Input or accessions in the first LOS cell require special considerations. Decisions made affect continuation rates and promotion rates directly in modifying the transfer matrix A. These policy decisions are coupled with a VRB or separation pay when these continuance rates are raised or dropped from those normally expected historically. This cost is noted and added into a total cost determination model.

For any given set of decisions, the solution to $x = Ax$, the steady state, can be found recursively. Adjunct costing models calculate the base case costs, and the cost of deviating from base case continuance rates is calculated. The Per Capita Cost Model develops the unit cost of personnel including retirement by pay grade and LOS. The Elasticity Dependency Model calculates the penalty premium paid for changing continuance rates either upward or downward. A utility model represents

a linear production function which simply sums the utility of each man as determined from the Delphi questionnaire. Utility $S(x) = S \times x$. Various constraints of the requirements type are included.

The objective of cost/productivity in units of dollar per utile is calculated for the current force in steady state. A nonlinear gradient search technique is used employing numerically calculated derivatives. Currently, during the test runs being made, the decision variables are limited to six continuance rates plus six pay grade promotion rates. Development of the model based on these test runs has not been completed and the model description is not yet available as a written publication.

GOAL PROGRAMMING IN THE NAVY'S OFFICE OF CIVILIAN MANPOWER MANAGEMENT

Requirements fixing the maximum and minimum number of men are specified over a planning horizon of around five years, taking the form of specifications on necessary manpower in each cell in each year distinguished by GS number and skill specialty area. Natural movement of population among cells is estimated and characterized by a transfer matrix A. Promotion rates and quotas also affect the transition matrix A. The motion is modeled as

$$x(t + 1) = A \times x(t) + L(t)$$

where L(t) represents the decisions to hire (recruitment) or fire (RIF) men in each cell at the end of year t.

Special staffing constraints (training limitations, etc.) on the system also apply. These originate from Congress or Navy Regulations. Budgetary and total-number-on-board constraints may also be applied. These may take the form of a constraint for each year.

Once initial conditions, x(0), are specified it becomes apparent immediately that no feasible solution exists to this set of linear equalities and inequalities. At this point no set of hiring or firing decisions can be found to satisfy the constraints starting from x(0). Penalty weights are then given for any absolute deviation from goals and operational constraints. Hiring and firing costs are estimated as well, and when combined with absolute deviations on user and institutional manpower requirements, make up a total linear objective function. This objective is minimized subject to the entire set of original constraints and law of motion. The decision variable is the hiring and firing variable $L_i(t)$ for each cell i and time t.

By ignoring the integer requirement on manpower, conventional linear programming codes can be used to solve for the time-dependent decisions on staffing levels to be made over the planning horizon.

INFINITE PROGRAMMING WITH APPLICATION TO NAVY ENLISTED FORCE MANAGEMENT

Accessions in year t are to be determined so as to minimize the present worth of future accession costs. Because only one skill category is considered at a time,

state descriptor variable x(t) is univariate and is the number of level men at year t. Requirements for each year are specified, which must be met or exceeded. This takes the form of $x(t) \geq R(t)$ for all t. Accessions in year t can be indicated by $x_0(t)$. Assuming that the surviving fraction of men from year to year is time-stationary during the whole planning horizon, we can write

$$x(t) = \sum_{j=0}^{t-1} a_{t-j}x(j) + x_0(t)$$

where $a_{t}m_{j}$ is the fraction of men entering in year j that survive to year t.

When costs are c to hire an individual in any year, and the discount factor is δ ($\delta = 1/1 + i$), the objective is

$$\sum_{t=0}^{\infty} x_0(t)\ \delta^t c\ .$$

All constraints and the objective function are linear in the decision variables and are coupled with the infinite planning horizon; this problem is called an infinite linear program. In certain cases where stationary long-run requirements apply, conventional linear programming can be used to find the optimal accessions pattern. The authors work through several examples.

THE ENLISTED PERSONNEL PROJECTION AND SIMULATION MODEL

State description vector x(t) breaks the force down only by length of service. Deterministic movement among these cells is characterized by the Markov transition matrix A, which contains reenlistment or continuance fractions. These linear equations are recursive and can be solved easily. The primary decision variable is cohort size, that is, the accession rate, $x_0(t)$, the entering class for each time t.

Again, $x(t + 1) = Ax(t)$ with manpower decisions specifying accessions $x_0(t)$ to be made.

Transition fractions within the A matrix are known to be functions of pay; for model simplicity, they are made functions of cohort size. The larger the size, the lower the retention rate. For example,

$$a_{t,t+0} = \lambda_t + (1 - \lambda_t)x^*_0/x_0(t)$$

where x^*_0 is the natural number of accessions, and λ_t is a constant. In this way reenlistment behavior is made a function of a system decision variable, cohort size. Although military wage, civilian unemployment, and earnings may also be deemed useful for incorporation into the reenlistment rate, this places too large a demand on computer time, and furthermore, the parameters of such a model cannot be accurately estimated because of lack of data. This attempt here does incorporate reenlistment behavior matrix A as a function of cohort size, and thus still maintains the linearity necessary in models to solve for the optimal accessions using linear programming.

Productivity, S(x), is measured by a total effectiveness function that is linear; it is found by weighting men of different LOS categories and adding. One example is to give a weight of zero to noneffectives (students, prisoners, patients, those on vacation) and a weight of one to effectives.

Costs are similarly a linear function of the state description x. Retirement is included in current costs by proportioning this pay over the earlier years.

The EPPSM can be used in a simulation mode, projecting the force age structure, productivity, and cost over time. In its optimization mode, not yet implemented, the accession pattern can be found to maximize effectiveness subject to a cost constraint. Currently, the constraints on the system are in vector form,

$$C_t \times x(t) = R_t,$$

representing yearly budget both during transient and steady-state years and other side conditions. They dominate the solution. It would be only accidental if $C_x = R$ had a set of accessions satisfying the constraints of the system. A weighted sum of squared deviations from these equalities is used as a penalty function and can be solved directly using matrix theory and weighted least squares.

SELECTIVE REENLISTMENT BONUS

The Objective Force Model is a mathematical procedure for determining the optimal size and composition of the force. The model distinguishes the state of the system by a vector x(t) with military occupational specialty, grade, and length of service characteristics. Entire groups of specialties, called career management fields, are handled collectively since a certain amount of cross-movement exists with these fields. Promotion, staffing, and grade limitation requirements are specified and linear programming is used to minimize the deviation of the modeled from the objective force. No detailed mathematics of the model were available in time to be reviewed in any detail here.

Appendix B

DISCOUNTING IN MANPOWER PLANNING

The calculation of total present worth (P.W.) has long been held to be the correct way to analyze a time sequence of payments. This criterion is actually a function that collapses the multidimensional revenue and cost vector into a single variate so that decisions can be based on its magnitude. Ranking projects or alternative policies without the P.W. criterion is the same as the classical problem of choosing the best basket of mixed fruit.

When the payments in a time stream are all precisely equal (which commonly occurs in certain deterministic steady-state situations), the average cost (or revenue) criterion can be used to order alternatives. To demonstrate that fact, let A_t be the payment in the t^{th} year of project A. Then

$$P.W._A = \sum_{t=0}^{\infty} \left(\frac{1}{1+i}\right)^t A_t \,.$$

Now when $A_t = A$,

$$P.W._A = A\left[1 + \frac{1}{i}\right] \,.$$

Thus under constant series of payments, any ordering of projects based on present worth will be the same as ordering based on annual cost A, independent of the interest rate. Under these conditions the average rate, sometimes called the average annual cost criterion, becomes a valid surrogate criterion for judging alternatives.

Any measure of performance to be used as a surrogate for the total present worth criterion must rank policy alternatives in the proper order to be judged valid. This alternative measure of performance may be easier to calculate or may be more familiar in the environment of the decisionmakers.

A measure symbolized by G and named, for want of anything better, the "total expected present worth of all future military pay," has been used in decisionmaking by manpower planners. It is used as a measure of performance for judging governmental manpower decision alternatives with regard to retirement, pay, continuance and reenlistment rates, etc. If p_t is pay an enlisted man receives in year t, r_t is continuance rate from year 0 to t, and X_0 is the number of annual recruits, then

$$G = X_0 \cdot \Sigma\, r_t \left(\frac{1}{1+i}\right)^t \cdot P_t \,.$$

G is therefore an approximation of the expected present worth of the total of the individual's revenue from the military.

To be a valid performance measure for governmental decisionmaking, G must mimic the ranking of alternatives made by the present worth criterion. Consider

two manpower plans, A and B. Plan A attracts 100 recruits per year at $1,000 per year. At the end of four years, plan A proceeds to reenlist 50 per year in the career force at a salary of $2,000 per year. The career force retires at 20 years, each retiree receiving annual retirement pay of $1000 per year for 25 years. Plan B maintains the same total number of men on the force (1200) by recruiting 150 per year and retaining 25 percent, or 37.5 men per year, in the career force under the same pay schedule. The resulting figures for cost and present worth are therefore as follows:

	A	B
Average Annual Cost	3,250,000	2,740,000
Total P. W. @ 10%	32,500,000	27,400,000
G	919,000	927,000

Criterion G incorrectly prefers A over B. The conclusion is that G is not a valid measure of performance.

Another criterion, H, termed the individual's expected total present worth equal to G divided by X_0, would properly rank plans A and B. Under A, H is $9190 and under B, $6180. However, this is not a valid measure either, as can be seen by using the following plan C, which reduces accession requirements and achieves 100 percent continuance rates by increasing expected total present pay, H, to $13,170. First-term pay is increased to $1200 and second-term pay decreased to $1500. Total manpower is maintained at 1200 men or 60 in each year of service. Under H, manpower planners would choose A, while under the valid total present worth, plan C is preferred.

	A	C
Average Annual Cost	3,250,000	3,230,000
Total P. W. @ 10%	32,500,000	32,300,000
H	9,190	13,170

Under transient conditions and under natural randomness, a system's costs vary year by year. In this case the total expected present worth of military manpower costs must be used to judge or compare alternatives rather than average annual costs.

Another area of debate when using discounting lies in calculation of the proper interest rate to be used. It is well known that this is a critical determinant of optimal policy when yearly costs are changing. If costs are rising at 4 percent a year because of inflation, and the true interest rate is 6 percent a year, the total present worth is calculated using 10 percent interest. In constant dollars, however, only 6 percent should be used. Since retirement and career pay are rising with inflation, the magnitude when actually received will be higher because of inflation. The proper interest rate for comparing alternative plans in terms of 1974 constant dollars is only 6 percent based on today's pay schedules. An alternative would be to use 10 percent per year based on extrapolated inflated pays received in subsequent years from now. Substantial literature exists in the field of economics on this topic.

If a constant string of payments—say, a bridge toll of $1.00—is to be made over some life of a bridge, then discounting to present worth in constant dollars should include inflation plus true interest. This would be about 10 percent. Executive

Order A-94, March 1972, from OMB directs the use of a 10 percent interest rate for cost analysis of this type. However, if that toll were somehow rising with the consumer price index, then the proper discount would be at a six percent rate. This latter is the case with military pay and retirement, which rises by law.

Criterion H, the individual's expected discounted present worth of future pay or the individual's maximum present worth (assuming 100 percent continuance rates) from the military, might be relevant to individual decisionmaking. In electing to enlist, and at each reenlistment point, this present worth is considered. In a simplistic model, the individual weighs the discounted return in military versus civilian service and chooses the greater. Manpower policy planners need to estimate functional relationships between some form of pay such as this and reenlistment behavior. This is the so-called manpower supply function. The individual's present worth of military pay should be found for every alternative personnel plan in order to verify that accessions and reenlistments can be maintained at desired levels, given the perceptions of pay under each alternative.

Unfortunately, studies have determined that even economics professors at the Air Force Academy do not have a correct estimate of the value of their military pay package. Manpower modelers, in assuming that the ordinary individual uses some way of discounting the future approximated by the calculus of discounting, are not accurately modeling the economic behavior of individuals. On the average, perhaps the use of discounting is more valid. Another well-known factor in economic behavior is the fact that most individuals are averse to risk. Here, risk is variability in pay. For example, while the expected present value of retirement from the organization's point of view may be \$5000, it never proves to be exactly \$5000. It may be, say, either \$10,000 or zero because fifty percent make it through to retirement and the other fifty percent receive nothing. Large corporations and the U.S. Government should be and are nearly risk-neutral. Some corporations are risk-preferring. And the individual who gambles at Las Vegas is demonstrating risk preference, but he enjoys the game and pays for his pleasure.

To achieve the same utility of a series of payments to an individual, a higher mean is required if the variance of that return is higher. In most manpower models to date, expectation of pay has been used in functional relationships with retention. Criterion H or its equivalent can be used as the expected pay in this regard but eventually should be supplemented by a utility measure including the variance of military pay as well. It is thought that individuals with low-risk preferences prefer military service as opposed to civilian life even though they forgo some expectation of earnings. Thus the U.S. Government, by providing a more certain working environment, can reap the benefits of paying lower salaries.

In the area of retirement pay, however, effectively the opposite is true. Because of the lack of vesting and uncertainty throughout the career until the last day of the twentieth year, the individual's risk-aversion depreciates the expected value of retirement. The U.S. Government must pay a higher average annual retirement bill to retired military people as a result of the variance of retirement payments.

These individual present-value calculations can at best be used properly *only* to predict individual enlistment and reenlistment behavior. Using them for government planning, as we have shown, can cause more expensive manpower plans to be adopted.

Appendix C

QUESTIONS FROM THE "MODEL EVALUATION WORKSHEET," BY NAVAL PERSONNEL RESEARCH DEVELOPMENT LABORATORY, APRIL 1973[1]

INPUT TO MODEL

1. Is the input required so voluminous and/or difficult to obtain as to pose a major factor to consider before using the model? If yes, consider the feasibility of running the model with incomplete input data and, if feasible, the effect on the model's validity and output. Also discuss the feasibility of modifying the model so as to require less data.

2. Is an adequate source of appropriate input data known to be available for which the accuracy, consistency, and timeliness have been well established?

3. Does the model presently receive data from other computer models? If yes, give an indication of the nature and physical form of the data and supply sufficient information on these models as to permit their location for possible evaluation.

PROCESSING BY THE MODEL

4. Has a sound basis been laid by the model builders for any nonstandard modeling techniques used or any innovative application of standard ones (e.g., if a model uses an iterative computational technique, have the necessary and sufficient conditions for convergence been established)?

5. Is the level of sophistication of the technique unnecessarily high or too low for the needs of the application area?

6. Is the modeling technique appropriate to the application area (e.g., if linear programming is used do the elements being modeled really behave sufficiently linearly)?

7. Is the model known to be deterministic or, if it is stochastic, is it known to be reliable?

8. Do the modeled system elements (e.g., blocks in the flow diagram) accurately reflect what actually exists in the application area?

9. Do the modeled system processes (e.g., connecting lines between blocks in the flow diagram) accurately reflect what actually happens in the application area?

10. Is the level of detail appropriate for the application?

11. Are all the values assigned to parameters such as work rates, fatigue factors, storage capacities, etc., correct?

12. If certain parameters are approximated, has an error analysis ever been performed to determine the cumulative error throughout the model caused by these approximations?

13. Is it known for what parameter and input values the model is valid and for which values (possibly extreme) it is not?

[1] Source: Refs. 1 and 2.

OUTPUT OF THE MODEL

14. Does the model presently feed data to other computer models? If yes, give an indication of the nature and physical form of the data and supply sufficient information on these models so as to permit their location for possible evaluation.

15. Is the output presented in such a way that a noncomputer oriented manager can with little or no training use it?

GENERAL

16. Are there readily available results from sensitivity studies showing the reaction of the model's major outputs to changes in at least the major parameters wihin the reasonable ranges of values for these parameters?

17. Has the model been adequately validated by a comparison of is results with events in the actual situation it attempts to model?

18. Has the model ever been subjected to rigorous tests or analyses such as might be performed by a technical person uncertain about or even opposed to the model?

19. Were the objections or questions raised resolved in such a way as to give credibility to the model?

20. Is the model capable of and worth being expanded or otherwise improved so as to be of greater benefit?

21. In view of the time, effort, and money expended in the use of the model and the benefits actually derived in the application area, is the continued use of the model warranted?

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This paper

Critically examines 26 military manpower models in light of their ability to aid planners in managing an efficient military force. This subset was selected from the more than 200 extant military manpower models. The report surveys the state of the art and describes the decision environment of models of this type. An overview of the individual models is followed by criticisms and recommendations for the future. The last two chapters contain a more classical survey of each of the 26 models, their theory, objectives, and operating characteristics. The appendixes examine specific ideas in greater detail. (Author)